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DoD Corrosion Prevention and Control Program

Measuring the Rate and Impact of Corrosion on DoD Equipment and Facilities

Final Report on Project AR-F-311 for FY05

Susan A. Drozdz, William H. Abbott, and Jana L. Jackson June 2007

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Measuring the Rate and Impact of Corrosion on DoD Equipment and Facilities

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Final report

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Abstract: This report documents a corrosion rate study performed for the Office of the Secretary of Defense (OSD) under the Corrosion Prevention and Control Program (CPC) in which standardized coupon test racks were set up in numerous marine locations at military and other government installations in the United States and overseas, including test sites on Navy and Coast Guard ships. The test sites encompass a large variety of locations, both in open exposure and sheltered environments. The principal objective of the study was to collect a large, standardized sample of data to be used in subsequent development of a computer-based model and corrosion-rate prediction tool. An analysis of the collected data indicate that corrosion rates decrease significantly when an installation's distance from an ocean exceeds 2 miles. The data analysis also shows that corrosion rates for military equipment can be reduced even by providing a simple shelter.

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Introduction

This demonstration was performed for the Office of the Secretary of Defense (OSD) under Department of Defense (DoD) Corrosion Control and Prevention Project AR-F-311; Military Interdepartmental Purchase Request MIPR5C6AG3CPC1, dated 29 December 2004. The technical monitor was Daniel J. Dunmire (OUSD(AT&L)Corrosion).

The work was performed by the Materials and Structures Branch (CF-M) of the Facilities Division (CF), Construction Engineering Research Laboratory – Engineer Research and Development Center (ERDC-CERL). The Project Manager was Vincent F. Hock. The contract portion of the work was performed by Battelle Memorial Institute, Columbus, OH, under the direction of William H. Abbott.

At the time this report was published, the Chief of the ERDC-CERL Materials and Structures Branch was Vicki L. Van Blaricum (CEERD-CF-M), the Chief of the Facilities Division was L. Michael Golish (CEERD-CF), and the Technical Director for Installations was Martin J. Savoie (CEERD-CV-ZT). The Deputy Director of ERDC-CERL was Dr. Kirankumar V. Topudurti, and the Director was Dr. Ilker Adiguzel.

COL Gary E. Johnston was the Commander and Executive Director of ERDC, and Dr. James R. Houston was the Director.

Executive Summary

This project is an extension of corrosion rate assessment studies conducted by Battelle Memorial Institute, Columbus, OH, over the past decade in support of the U.S. Air Force Air Vehicle Heath Management Program. The project documented here encompasses 139 new sites representing military other government assets, including Army, Navy, Coast Guard, and National Aeronautics and Space Administration (NASA) facilities, and Navy and Coast Guard ships. Sites were distributed across the military services as follows:

Service/Agency	No.
Army	40
Coast Guard	15
Air Force	45
Navy	11
NASA	8
Other	20
Total Sites	**139**

The results show that the corrosion rate of military equipment can be reduced by providing even a simple shelter. At military sites near the ocean, corrosion rates decrease significantly when the distance from the ocean is greater than 2 miles. It is not surprising that chloride levels make the marine sites more corrosive than rural sites away from the ocean, but humidity and duration of wetness also play a role.

1 Background

Overview

Throughout the world, corrosion maintenance is most often based on finding and fixing the damage prior to its becoming a structural or safety concern. The Department of Defense (DoD) has identified this approach as inadequate to meet mission criticality, e.g., equipment and facilities availability to support deployment, training, and readiness.* Little emphasis has been placed on the development of engineering tools needed for the management of this corrosion and the associated maintenance and repair actions. The benefits and longevity of corrosion prevention and control measures have not been quantified, so optimization of these actions has not been possible. As DoD fleets and facilities have aged, the life limiting degradation mechanisms have shifted from those associated with usage to those associated with time. The costs of corrosion maintenance have risen drastically. Furthermore, the concerns for corrosion, which previously had centered on cost, have now begun to include structural integrity and safety. This shift has dictated a change to a prediction and management approach beyond just simply finding and fixing.

Corrosion monitoring activities were undertaken at a number of military sites for the purpose of characterizing level and variability of environmental severity. This work was identical in terms of methods, analytical procedures, and data analyses to studies conducted by Battelle Memorial Institute, Columbus, OH ("Battelle") for the U.S. Air Force† in support of the Air Force, Air Vehicle Heath Management program. Under that work, coupon corrosion monitoring has been in progress at more than 150 military installations worldwide. Large databases have been developed to describe Environmental Severity Indices (ESI) for various sites to provide a basis for management decisions such as aircraft wash-rinse intervals.

The original plan was to conduct sampling at a minimum of 40 sites, distributed worldwide. Due to the level of interest shown by personnel at the test locations, however, a total of 139 new sites were added, representing

* Abbott, W.H., and Richard Kinzie. 2006. Aircraft Corrosion Sensing and Monitoring Program. Presentation at the 9th Joint FAA/DoD/NASA Conference on Aging Aircraft, 6-9 March 2006, Atlanta, GA.

† Abbott and Kinzie 2006.

DoD, the Department of Homeland Security (i.e., the U.S. Coast Guard), the National Aeronautics and Space Administration (NASA), and other facilities. Detail about each location is provided in Appendix A, and photographs of the sampling setups at representative installations are presented in Appendix B.

Summary of test locations

Army sites

Table 1 lists the primary Army sites and locations included in the study.

Table 1. Primary Army sites.

1. Bahamas, Exuma Airport
2. Baltimore, MD, Coast Guard Yard
Colombia, South America 3. Bogota 4. Riohacha 5. San Andres 6. Tres Esquinas
Fort A.P. Hill 7. inside magazine 2 8. inside magazine12 9. outside magazine 12
10. Fort Campbell, Kentucky
11. Fort Drum, New York
12. Fort Eustis, Virginia
13. Fort Hood, Texas
Fort Irwin, California 14. Barstow-Daggett Heliport 15. Bike Lake Airfield 16. El Grazio 17. Main Gate 18. Warehouse 19. Wastewater Treatment Plant
20. Fort Polk, Louisiana
21. Fort Rucker, Alabama
22. Fort Wainwright, Alaska
23. Hunter AAF
24. Hunter AAF

25. Little Goose Lock & Dam, Washington
26. Rock Island Arsenal, Illinois
27. Schofield Barracks, Hawaii
Vandenberg AFB 28. 1/4 mile* from shore, BDA/Boeing Building 988 29. 1/2 mile from shore, Rod & Gun Club, Building 1521 30. 1 mile from shore, SLC 6, Building 392 31. 2 miles from shore, Airfield 32. 7 miles from shore
Wheeler AAF, Hawaii 33. outside hangar 34. inside open metal hangar

In addition to the primary sites, the University of Hawaii contacted Battelle about sites involved in the Pacific Rim Corrosion Research Program sponsored by U.S. Army Tank-automotive and Armaments Command (TACOM). There are six test sites around Hawaii where corrosion studies are being performed and weather data are being collected, presenting a unique opportunity to obtain data for evaluating a recently developed corrosion model requiring inputs of both corrosion and weather data. Samples were installed in March 2005 at the six sites shown in Table 2

Table 2. Army TACOM test sites in Hawaii.

35. Campbell
36. Coconut Island
37. Ewa Nui
38. Kahuku
39. Lyon Arboretum
40. Waipahu

Coast Guard sites

Eleven shore-based Coast Guard installations were included as test sites, as well as two sites on two separate ships (four locations total). Two shipboard sites were in the open, above deck, and two were located in an aircraft bay. The shipboard data will be used to define the effect of sheltering on the corrosion rates for military equipment. Table 3 lists the participating Coast Guard sites.

* 1 mile = 1,609.347 meters.

Table 3. Coast Guard test sites.

1. Boston, MA
2. Humboldt Bay, Samoa, CA
3. Manistee, MI
4. Miami Beach, FL
5. New Orleans, LA
6. Portsmouth, VA
7. San Diego, CA
8. Seattle, WA
U.S. Coast Guard Cutter Bear 9. Above Deck 10. Hangar Bay
U.S. Coast Guard Cutter Harriet Lane 11. Above Deck 12. Hangar Bay

Air Force sites

Exposures at Tyndall Air Force Base (AFB), FL, inside and outside of aircraft/tent type shelter to examine effects of nominal sheltering on corrosion rates (two locations) were implemented in August 2005.

Exposures were placed at multiple locations at Sembach, Germany, indoors and outdoors, to examine quality of environments for storage of War Ready Materials (WRM). Four locations were implemented. Reports from the POC indicate very little reactions in storage locations. Samples indoors remain in place; the outdoor sample will be replaced only at 3 months.

A request was made from the Air Force POC to obtain data at a test site at Point Judith, RI. This site is owned by Alcoa, and a considerable amount of historical data has been obtained from it. It is believed that these data would be valuable to compare a number of well known test sites (including this one) to complement data being obtained at Kennedy Space Center (KSC), Key West, and Daytona Beach, FL. Agreement was reached with the POC at Alcoa, and two test racks were shipped to Alcoa.

Vandenberg AFB presented an important opportunity to conduct a study of corrosion versus distance from ocean, as planned for KSC. The 45 new Air Force sites are listed in Table 4.

Table 4. Air Force test sites.

Bermuda Biological Station for Research 1. Prospect 2. Station 3. St. David's Island
4. Dobbins AFB, GA
Hickam AFB, Hawaii 5. Test bench area, Bldg. 3386 6. Test bench area, Bldg. 3386 7. Quality assurance room, Bldg. 3386 8. Training Room #16, Bldg. 3386 9. Utility Station outside F-15 AGE shelter 10. Utility station off F-15 ramp Loko Drive 11. Utility station #1 inside Bldg. 1045 12. Inside Shelter #3, Bldg. 1045 13. Inside F-15 AGE shelter 14. F-15 sunshade shelter #16, 25 feet high 15. F-15 sunshade shelter #16, 12 feet high 16. F-15 sunshade shelter #10, 25 feet high 17. F-15 sunshade shelter #10, 12 feet high 18. F-15 sunshade shelter #08, 25 feet high 19. F-15 sunshade shelter #09, 12 feet high 20. F-15 sunshade shelter #02, 25 feet high 21. F-15 sunshade shelter #02, 12 feet high 22. HIANG/Wahiawa, Outside 23. HIANG/Wahiawa, Inside 24. Hangar 35, 240 feet from hangar door 25. Hangar 35, 60 feet from hangar door 26. Building 2025 outside
27. Kentucky ANG, Louisville, KY
28. Lackland AFB, San Antonio, TX
29. Long Island, NY 30. Long Island, NY
31. Mansfield ANG, Ohio
32. Moody AFB, Valdosta, GA
33. Patrick ANG, FFL
Point Judith, Rhode Island 34. Back of lot 35. Front of lot
Sembach Air Base, Germany 36. Building 15, humidity control 37. Building 16, heated in winter 38. Building 17, vented for POL trucks 39. Outdoors

40. Savannah ANG, GA
41. Stewart Air National Guard Base, NY
Tyndall AFB 42. Inside shelter 43. Outside shelter
44. Westover Air Reserve Base, MA
45. Yokota, Japan

Navy test sites

Discussions were held with Naval Air Command (NAVAIRCOM) during February 2005 about this project. Two unique opportunities arose: the helicopter carrier USS Gunston Hall (LSD 44) based in Norfolk, VA, and the aircraft carrier USS Nimitz (CVN 68) based in San Diego, CA. Both ship installations were incorporated into the current test program; those and the other Navy sites are listed in Table 5.

Table 5. Navy test sites.

1. USS Gunston Hall
USS Halyburton 2. Above deck 3. Below deck
USS Nimitz 4. Above deck 5. Below deck
6. Naval Air Station Sigonella, Italy
7 – 9. Naval Air Station, Whidbey Island, WA (3 sites)
Naval Air Weapons Station, China Lake, CA 10. under shelter 11. outside shelter

NASA sites

Discussions were held with the contractor managing the corrosion test site at KSC. They are prepared to assist in the placement of samples at the Navy facility at Key West and multiple samples at KSC. The purpose of the latter is to obtain new data on the effects of distance from ocean on corrosion rates. These installations (Table 6)were scheduled for May 2005 but

were postponed for a pending shuttle launch, then rescheduled for and installed the following month.

Table 6. NASA test sites.

Kennedy Space Center 1. Beach Corrosion Test Site 2. Beach, outside 3. 1/4 mile from shore 4. 1/2 mile from shore 5. 1 mile from shore 6. 2 miles from shore 7. 5.5 miles from shore
8. Key West

Other sites

Addition of test samples at Battelle's Daytona Beach test facility is another example of a severe coastal location and one at which a considerable amount of corrosion data have been developed in recent years. One reason for adding this site was to provide up-to-date data somewhat in parallel with the current studies. Table 7 lists those sites and two on behalf of the National Science Foundation.

Table 7. Other test sites.

National Science Foundation (NSF) Site Antarctic 1. Site 1 2. Site 2
Battelle Daytona Beach 3. Half-mile riverside fence 4. Beach site, 75 meters 5. Doghouse 6. Shelter: 2 ft from top 7. Shelter: 4 ft from top 8. Shelter: side 9. Shelter: top peak 10. 45 degree rack, ocean site 11. Upright near rack, ocean site
12. Ocean City, NJ
13. Laque, Kure Beach, NC
Perry, FL 14. Under shelter 15. Under shelter

16. Open field 17. Sun shade
18. University of Puerto Rico, Mayaguez
West Jefferson 19. 45 degrees 20. Upright

2 Lessons Learned

No difficulties were encountered in the location, setup, retrieval, or analysis of the corrosion coupon racks, so this chapter is not applicable to the project.

3 Technical Investigation

Approach

This work was conducted at ground-based Army, Navy, Coast Guard, Air Force, and NASA sites, and on Navy ships and Coast Guard vessels. The sites were determined by ERDC-CERL and Battelle in cooperation with the participating DoD activities and other agencies.

Once the test sites were established, the contractor made arrangements for the installation and management of test coupon racks. Each test card contained silver, copper, and 1010 steel coupons, and three aluminum alloys (2024 T3, 6061 T6, and 7075 T6). The silver content was included for acquiring a measure of atmospheric chlorides. Sample returns were analyzed for mass loss in accordance with American Society for Testing and Materials (ASTM) G1* and chlorides in accordance with ASTM B825†.

The host sites furnished suitable test rack locations at each of the selected installations. The contractor provided to each location a small “standard” test rack containing a single test card holding the metal coupons. This card was removed and returned to the contractor and replaced with a new card every 3 months over the course of 1 year. The exception to this practice was made for sites outside the continental United States (OCONUS). These sites were sent a larger rack with four cards. One card was removed each quarter and returned to the contractor for analysis. All management of the test racks was done through the mail using procedures already established in Air Force studies. The contractor was responsible for test rack preparation, mailings, arrangement for sample returns, sample analyses, and reporting.

Land-based sites

Data have been analyzed for some of the Army sites. Eventually there will be data for all of the metals being exposed along with the chloride data from silver sensors.

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* ASTM G1 Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.

† ASTM B825 Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples.

This particular work represents one of the few times where monitoring has been done at multiple locations distributed around a given installation. This series of tests was done as a result of an interest expressed by Fort Irwin personnel and their commitment toward deploying the test racks. The effort yielded some interesting data.

The data in Figure 1 show what is judged to be a small but real variation in atmospheric chlorides around the installation. The fact that chlorides were found at all may come as a surprise to some, yet the contractor's monitoring experience has shown that chlorides detected in this manner on silver sensors can be found at virtually any location in the world.

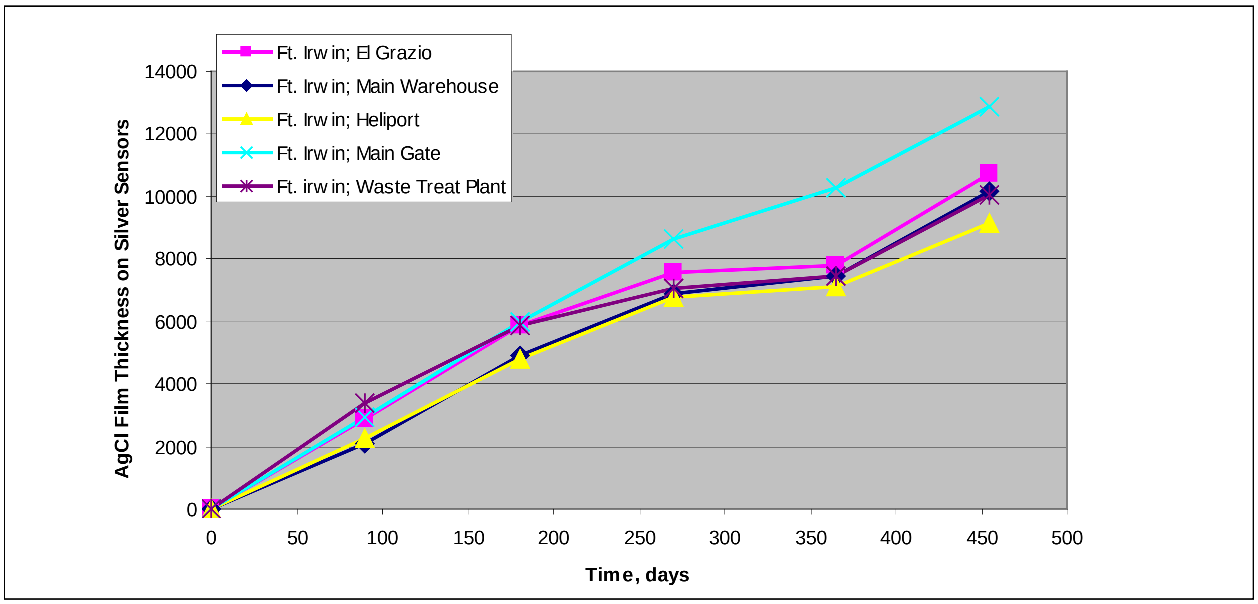

Figure 1. Atmospheric chlorides at various locations around Fort Irwin.

It is known that chlorides detected in this manner play a major role in the corrosion of metals. Several points should be noted, however. First, there is no intent to describe or determine what the source(s) or nature of the chlorides may be. It is generally assumed to be sodium chloride (NaCl), but other circumstantial evidence brings that assumption into question even for coastal locations. Second, as important as the chloride contribution to corrosion may be, it should be recognized that this is only one part of a complex, synergistic relationship between chlorides and other critical environmental variables. In particular, various measures of moisture in the atmosphere play a very important role.

Figure 2 shows the corrosion rates for 1010 steel at the various locations around Fort Irwin. The conclusions from these data are that (1) the data are relatively well behaved, and (2) what are considered small variations exist around the base. These variations can be considered to be due to local variations in chlorides and moisture and any analysis errors. What is not specifically shown in these data, but will be at a later date, is that, compared with similar data for the rest of the world, (1) these variations are truly small, and (2) the environmental severity at Fort Irwin is considered mild.

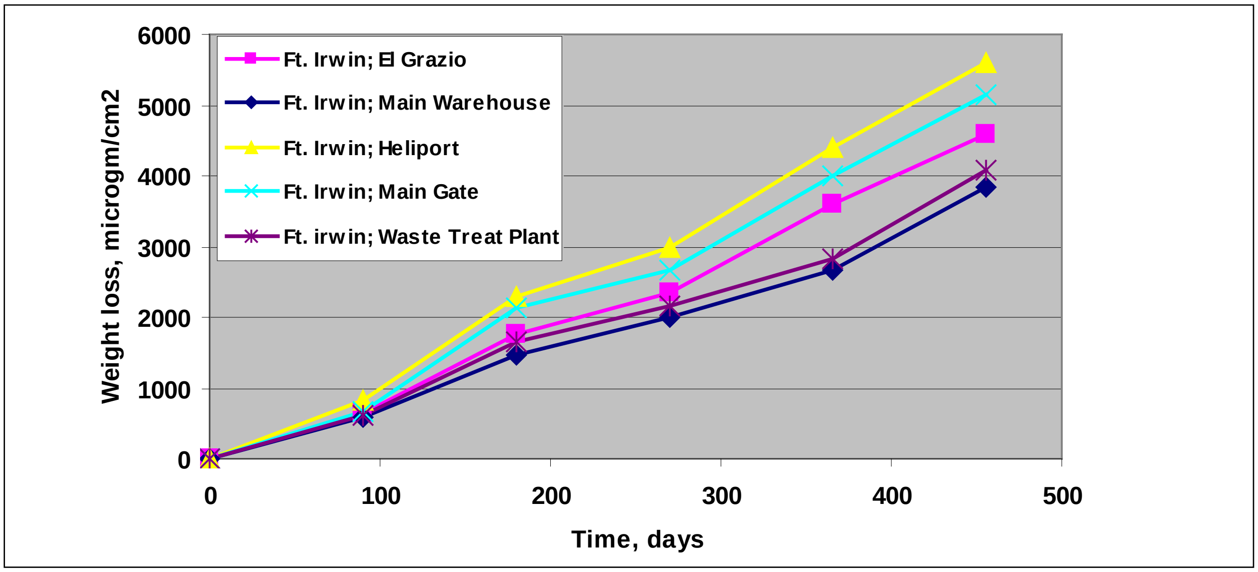

Figure 2. Corrosion of 1010 steel around Fort Irwin.

Figure 3 shows atmospheric chloride levels for other Army sites. These data are then shown in Figure 4 compared with a truly severe site at KSC. These data begin to introduce the following likely results from this work. First, among the sites surveyed, there is an expected/natural distribution of severity levels for Army sites. Among these, Wheeler AAF will probably qualify as one of, if not *the*, most severe. Second, compared with the other services, Army sites are likely to qualify as low to moderate severity. This finding is not to conclude in any way that corrosion is not an issue at Army sites. However, it is an attempt to place the atmospheric corrosion issues in proper perspective.

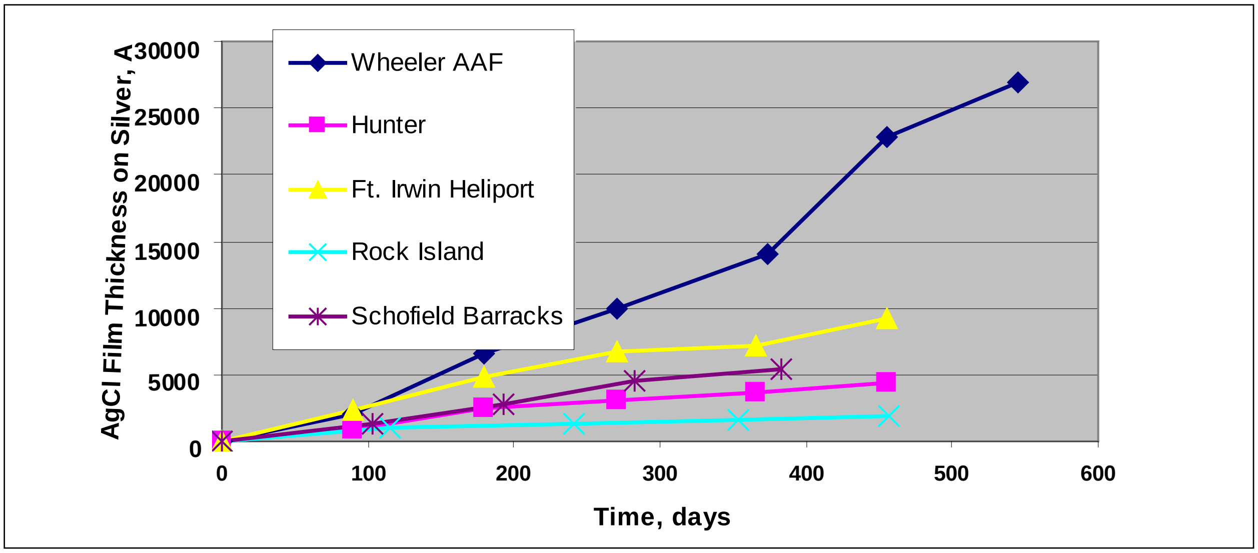

Figure 3. Atmospheric chlorides at additional Army sites.

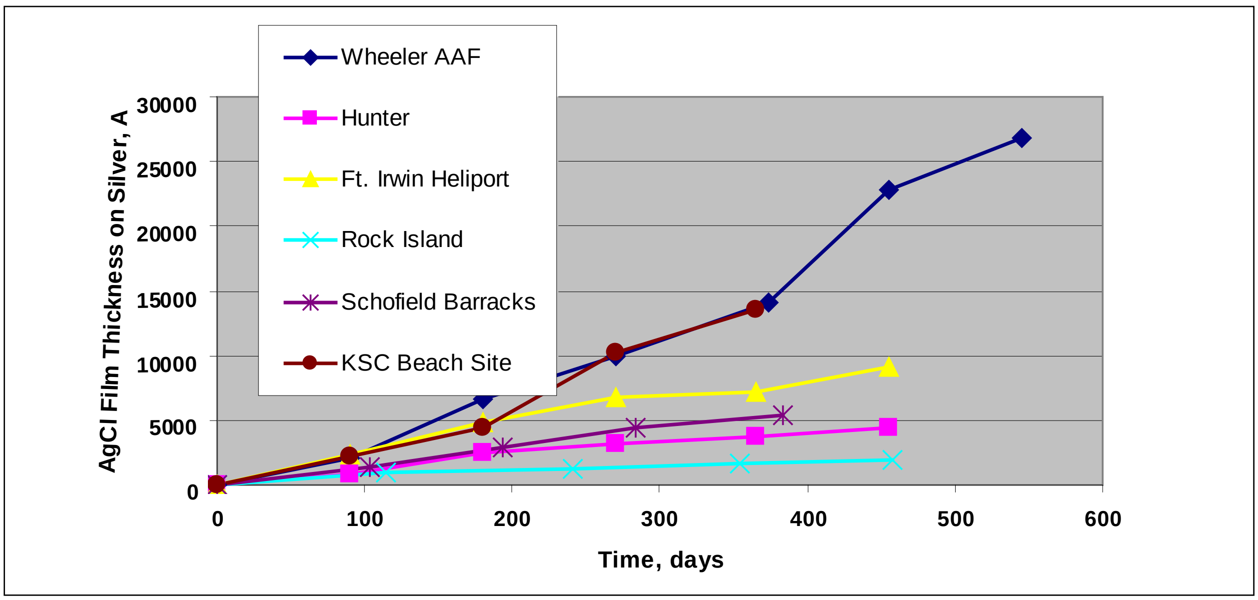

Figure 4. Atmospheric chlorides at Army sites compared to severe Atlantic coastal site.

Corrosion data are also shown in Figure 5 and Figure 6. Again, these data begin to show the likely distribution of Army site data. Also, the results in Figure 6 begin to show how Army site data may relate to any exposure tests run at KSC. These data may indicate that, in general, Army installations rank among the milder environments in terms of general corrosivity.

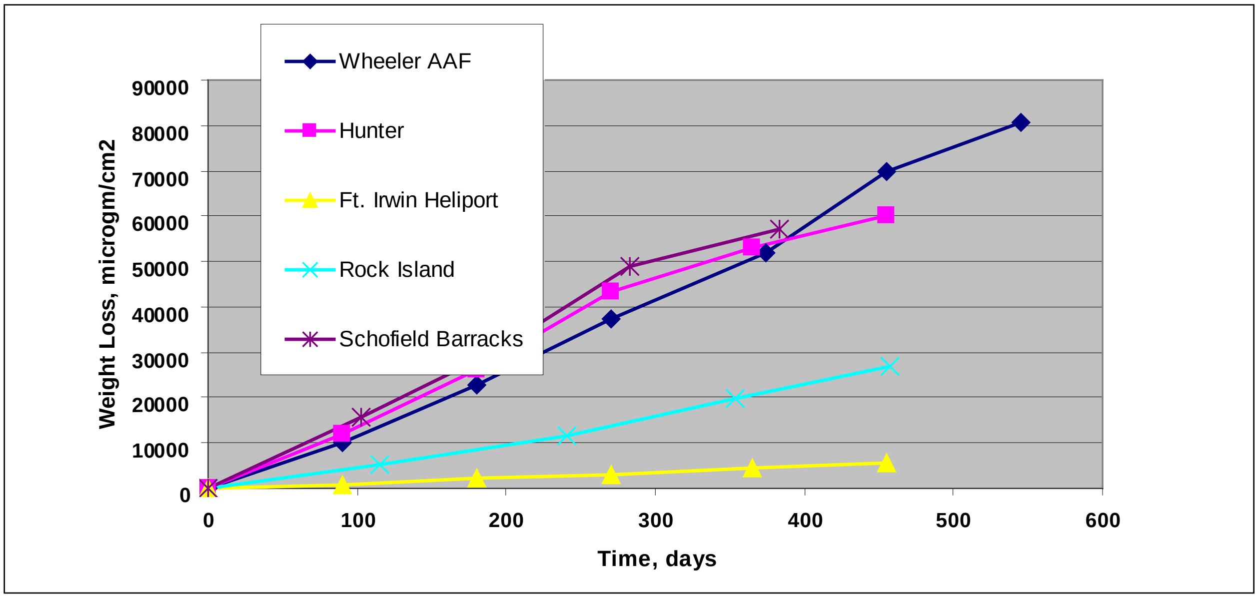

Figure 5. Atmospheric corrosion of 1010 steel at Army sites.

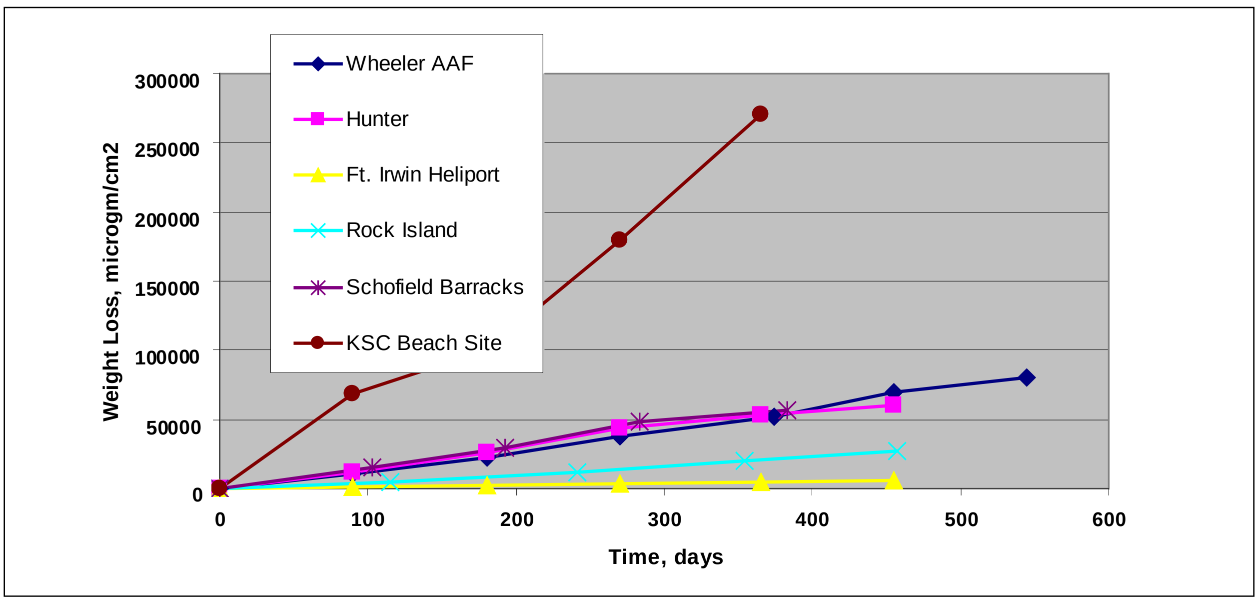

Figure 6. Atmospheric corrosion of 1010 steel at Army sites compared with a severe Atlantic coastal site.

Sites near the ocean

These data show differences among atmospheric chloride levels but far greater differences in corrosion rates. Attempts have not yet been made to examine these results against current corrosion models. if these models hold true, however, the corrosion differences would have to be accounted for by significant differences in relative humidity/time of wetness (TOW), and, to a lesser extent, rainfall.

It is not surprising that, compared to the land-based sites, atmospheric chloride levels play a more important role at sites near the ocean. Figure 7 – Figure 9 illustrate the chloride levels at various seaside locations, and the higher corrosion rates for aluminum and steel at these sites. One important point to note concerning these data is the necessity to clearly define where the samples are being exposed in relation to distance-from-ocean.

These new data tend to show very similar annual chloride levels among these particular sites. As shown in Figure 8 and Figure 9, however, the chloride levels alone do not account for the large differences in corrosion rates among the same sites/locations.

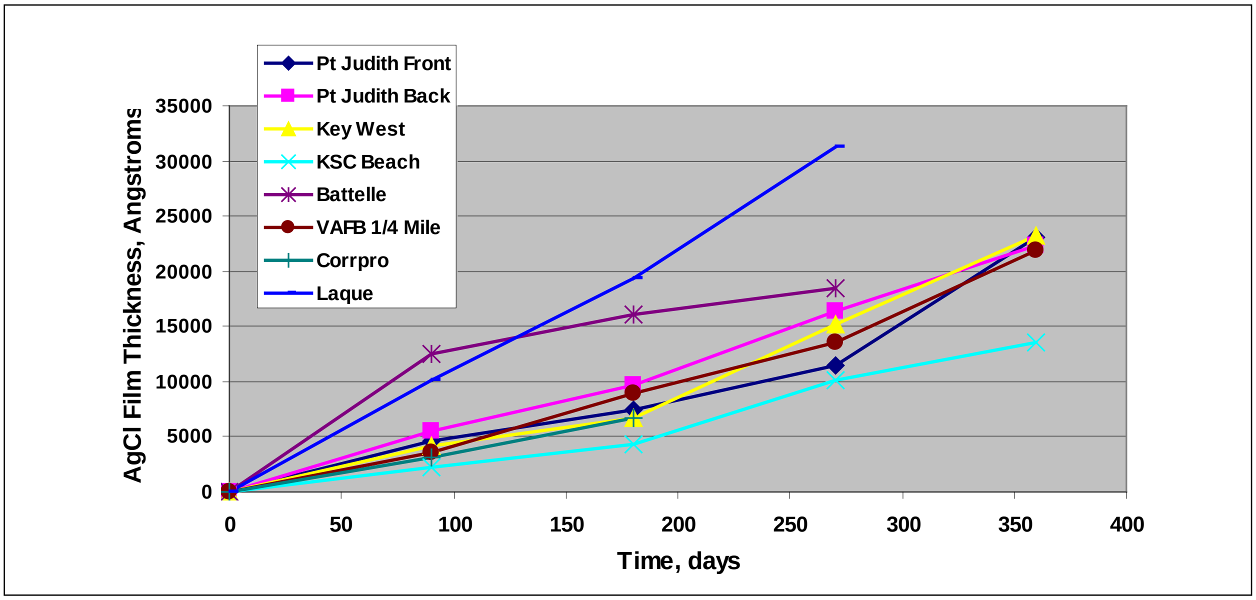

Figure 7. Site comparisons for atmospheric chlorides from silver sensors.

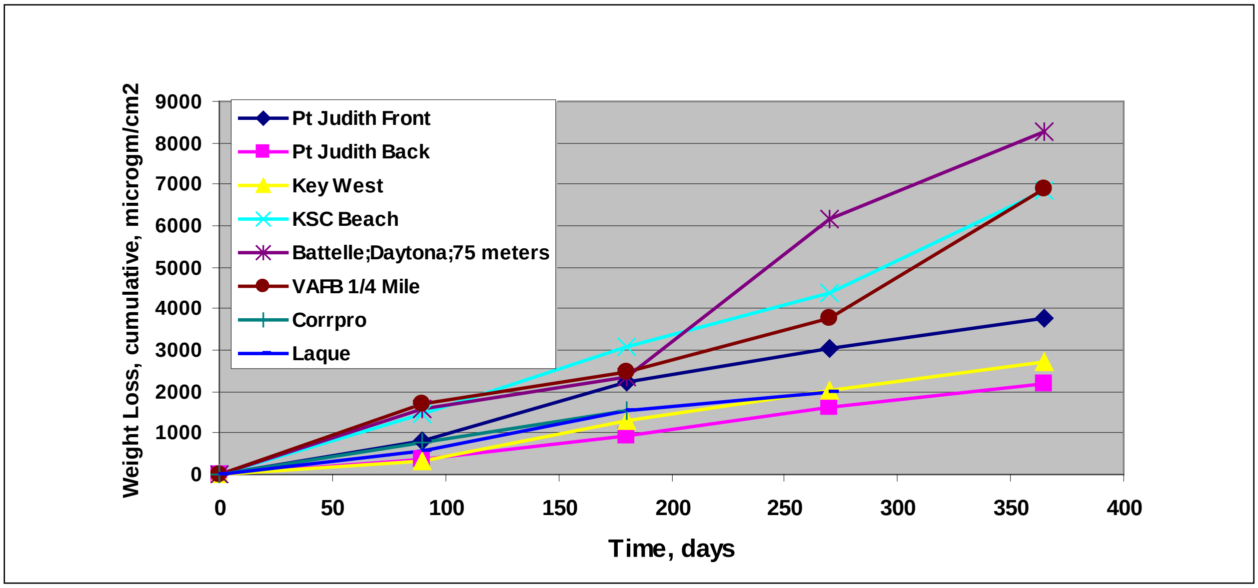

Figure 8. Comparison of test sites; corrosion of 2024 T3 aluminum.

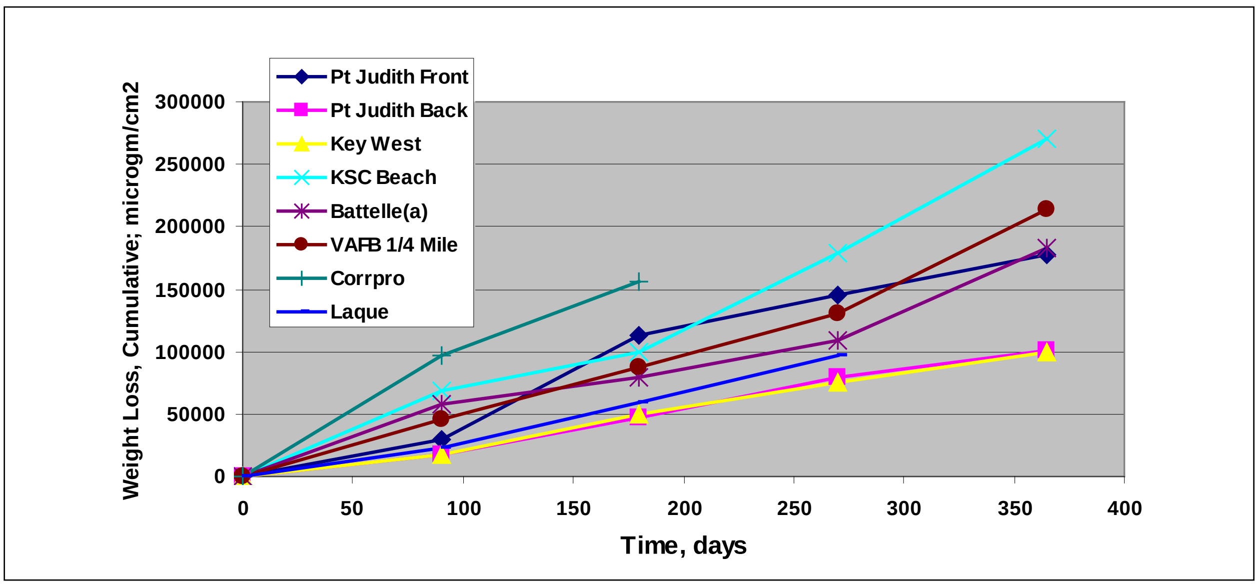

Figure 9. Test site comparisons; corrosion of 1010 steel.

Figure 10 – Figure 12 show similar data for various Coast Guard sites. These results show a wider range of chloride levels. Humboldt Bay, CA; San Diego, CA; and Miami, FL show similarly high chloride levels, but Humboldt Bay clearly ranks the highest for both aluminum and steel corrosion rates. Information is being obtained from these locations regarding distance from ocean for the point-of-sample placement in an attempt to understand these differences.

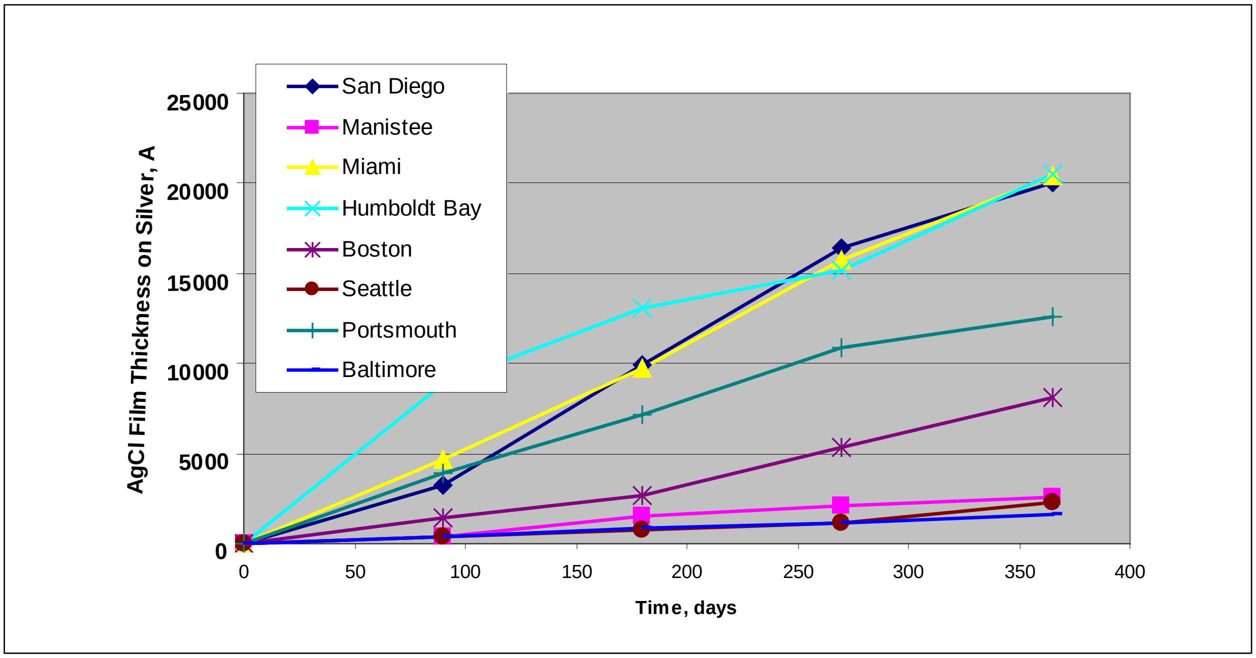

Figure 10. Chloride kinetics on silver sensors at Coast Guard stations.

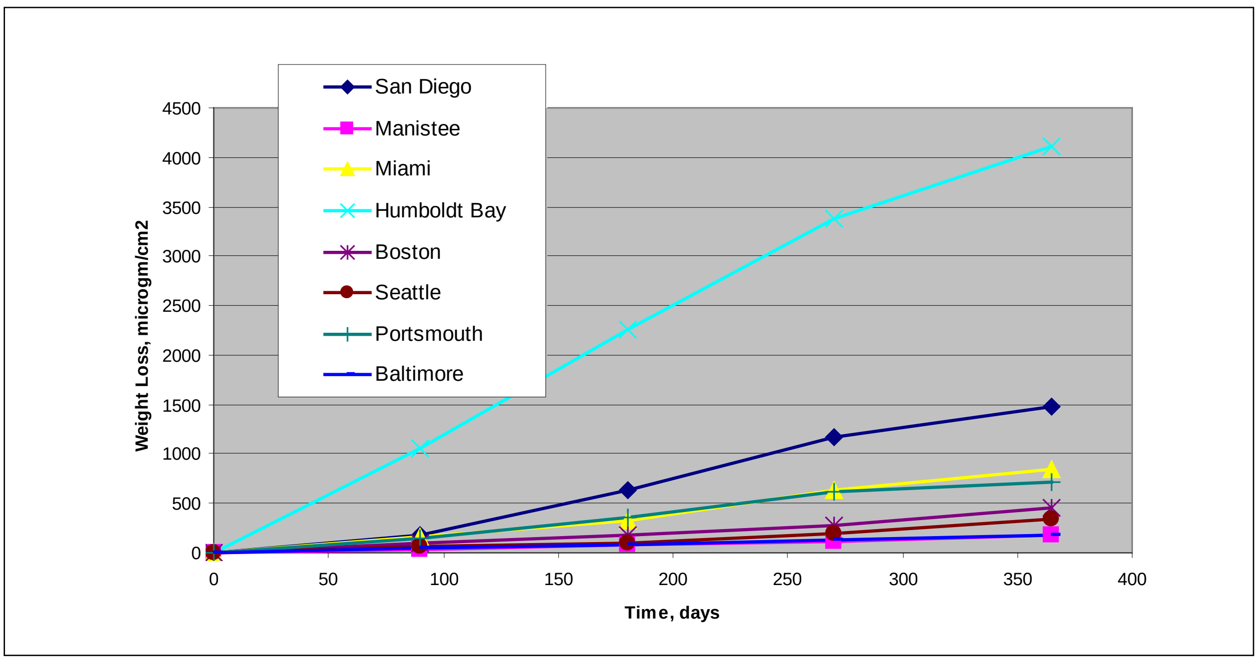

Figure 11. Corrosion of 2024 T3 aluminum at Coast Guard sites.

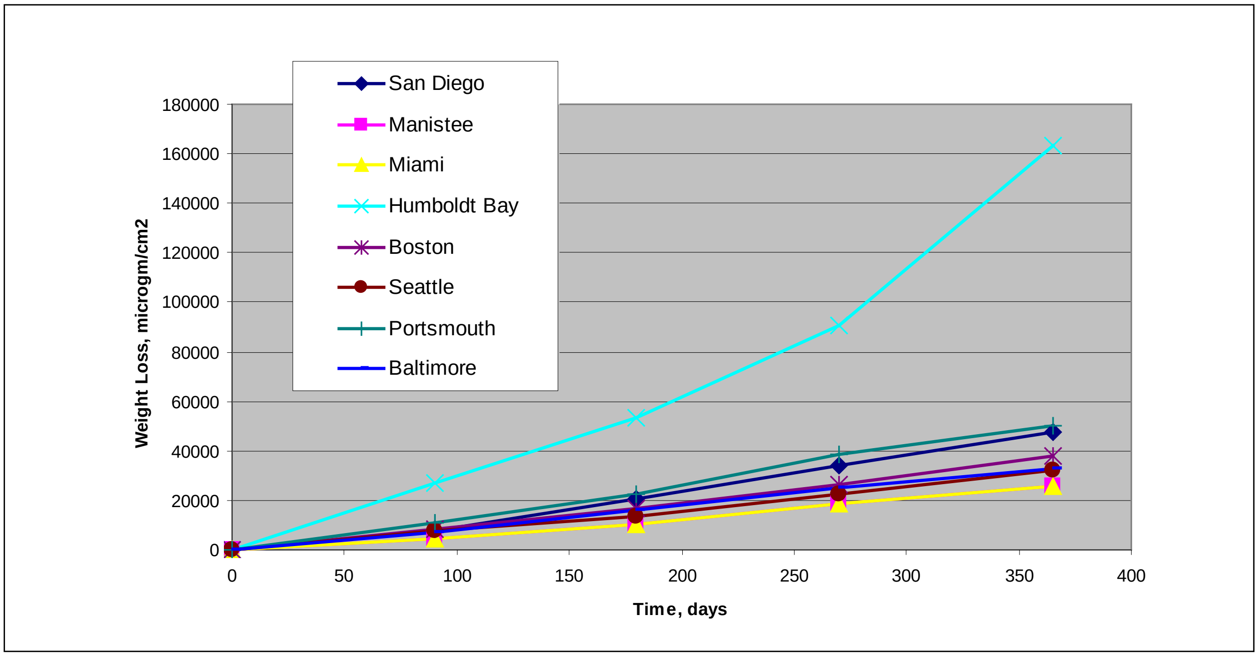

Figure 12. Corrosion of 1010 steel at Coast Guard stations.

Effect of distance to the ocean on corrosion rates

The placement of test racks at two sites — John F. Kennedy Space Center (Atlantic Ocean) and Vandenberg AFB (Pacific Ocean) — was intended to examine the relationships between corrosive severity and distance-from the ocean. These studies were done at distances ranging from a few meters from the ocean (KSC test site) to about 7 miles. The coupon test racks were identical to those used in all other studies, and, as far as can be determined, all samples were facing the ocean. Figure 13 – Figure 15 show results through 9 months, and Figure 16 – Figure 19 show the full year.

Several features are very clear from these data. First, and of no surprise, is the fact that chlorides and particularly corrosion rates show a sharp (and expected) decrease in chloride levels and corrosion rates as distance from the ocean increases. The sharpest portion of that decrease is well within the first mile and more generally within the first one-quarter mile. Attenuation factors are in the range of 7:1 – 8:1.

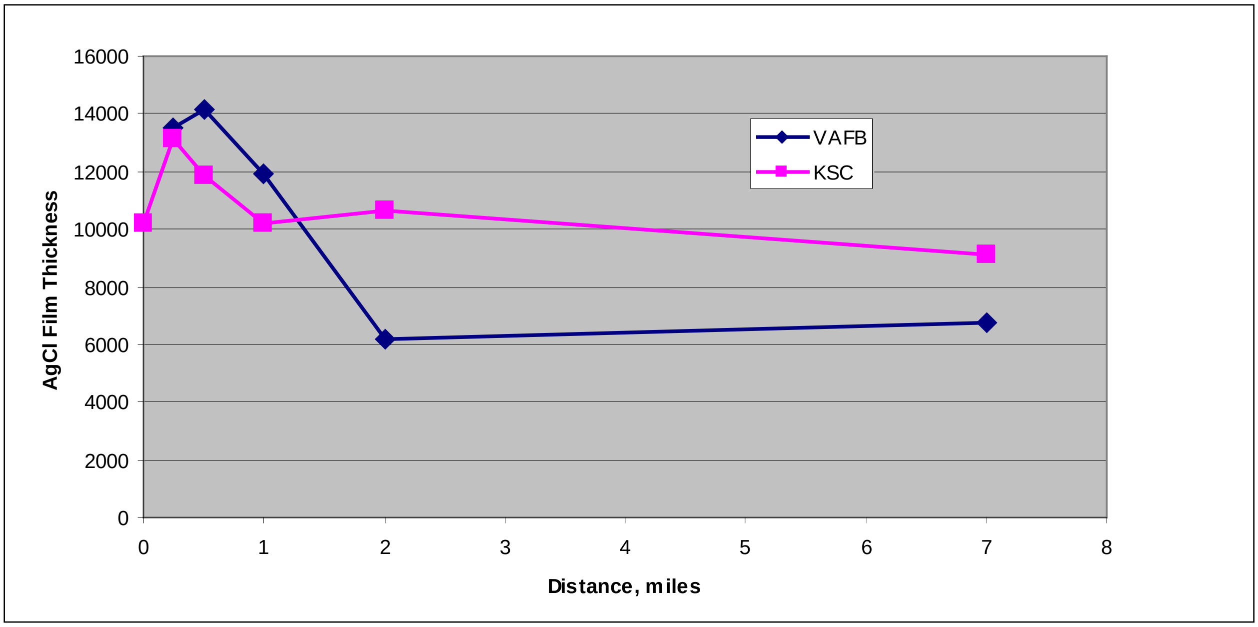

Figure 13. Chloride (from silver sensors) vs distance at KSC and VAFB; 9 month data.

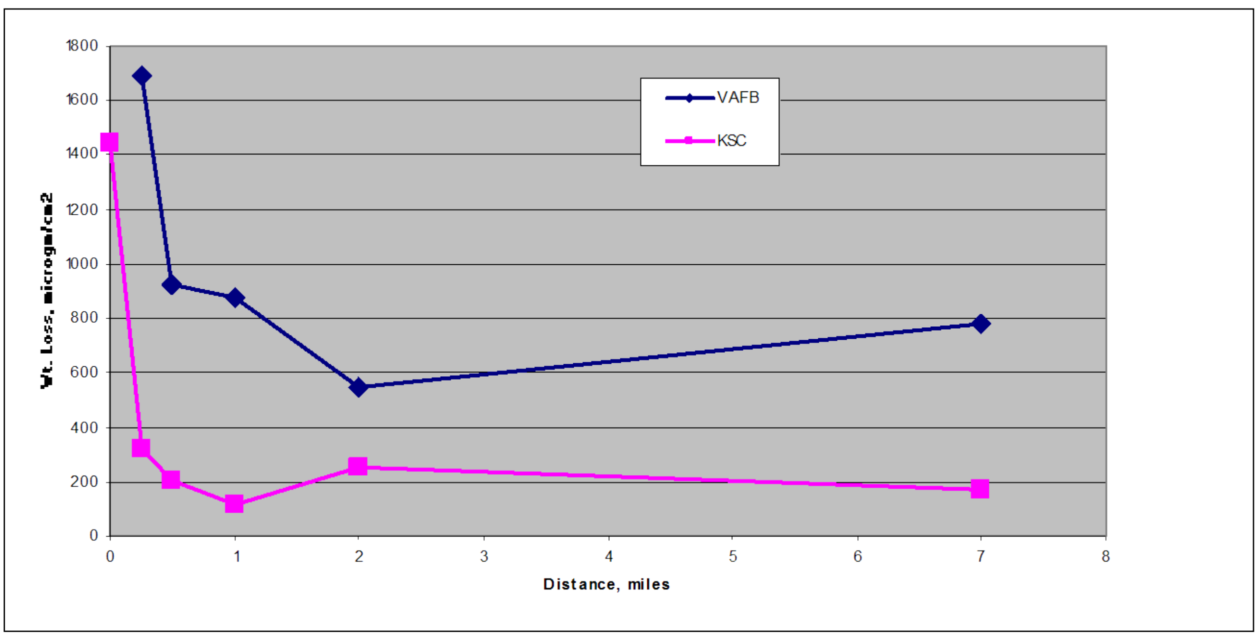

Figure 14. Corrosion of 2024 T3 aluminum at KSC and Vandenberg AFB; 9 month data.

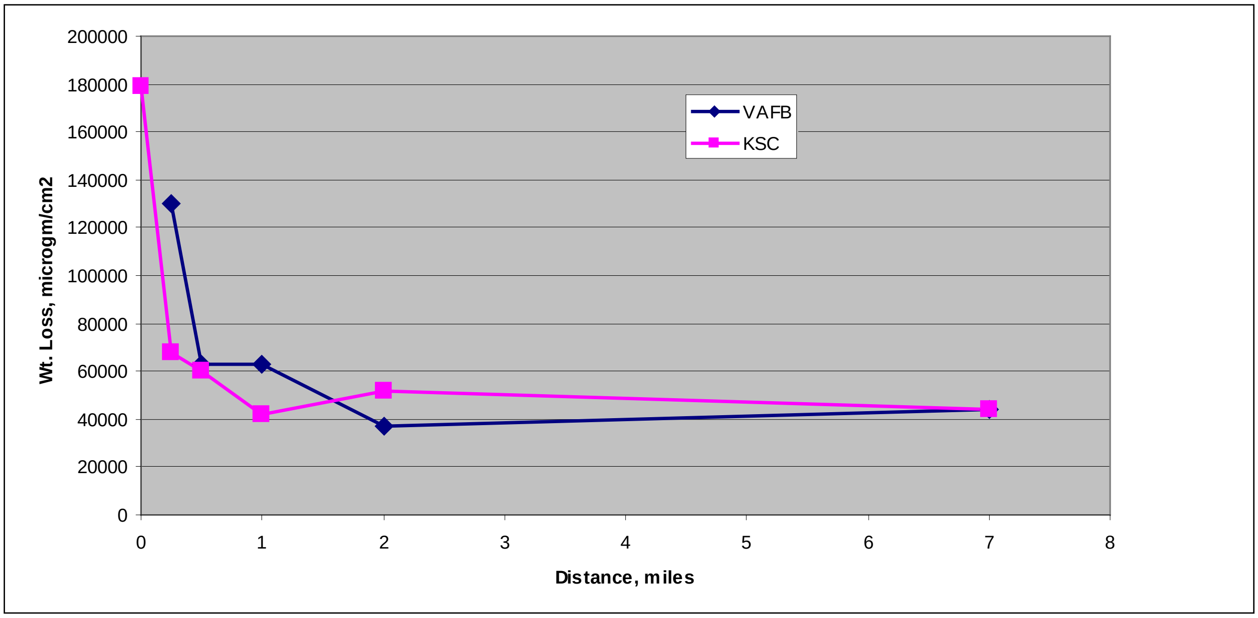

Figure 15. Corrosion of 1010 steel at KSC and Vandenberg AFB; 9 month data.

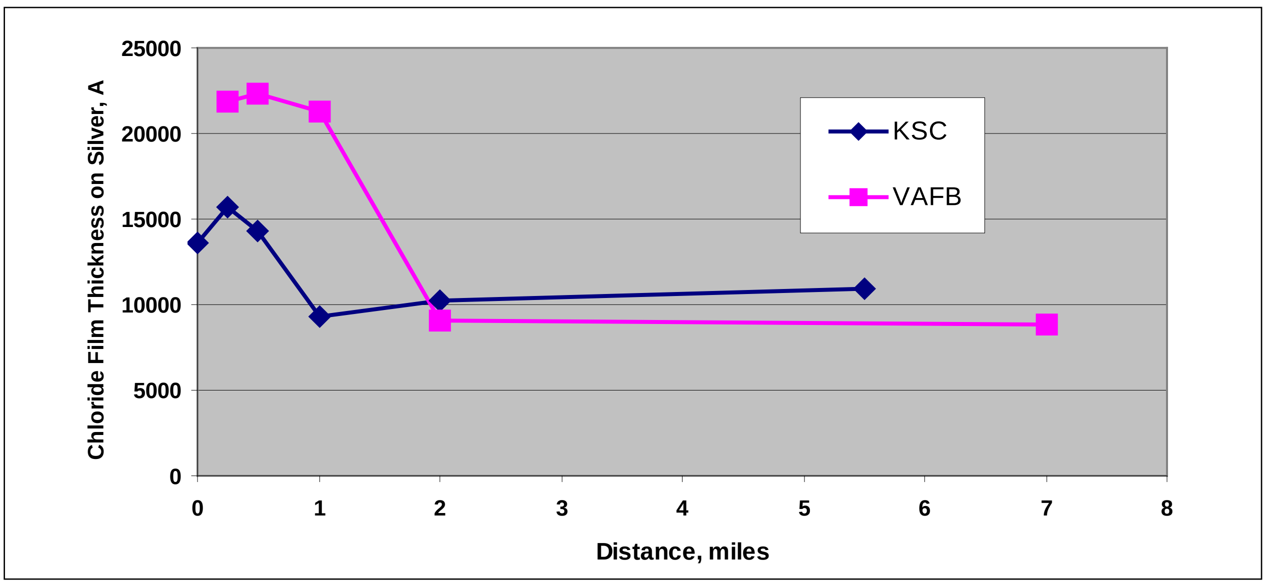

Figure 16. Atmospheric chloride vs distance from ocean at KSC and VAFB; 1 year values.

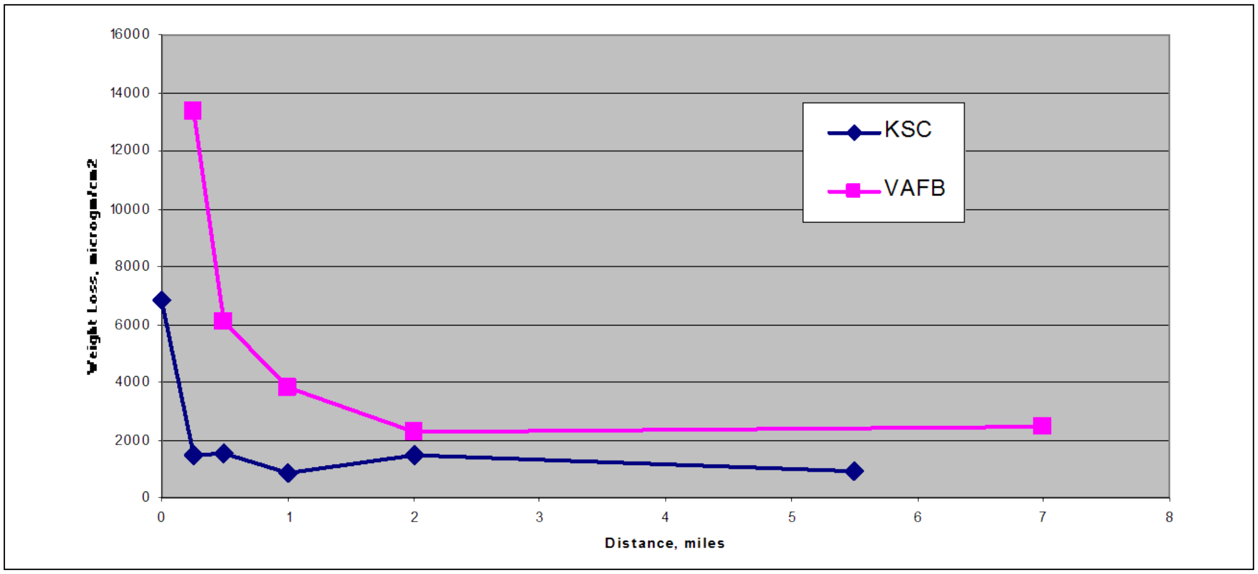

Figure 17. Corrosion of 2024 T3 aluminum at KSC and Vandenberg AFB vs distance from ocean; 1 year values.

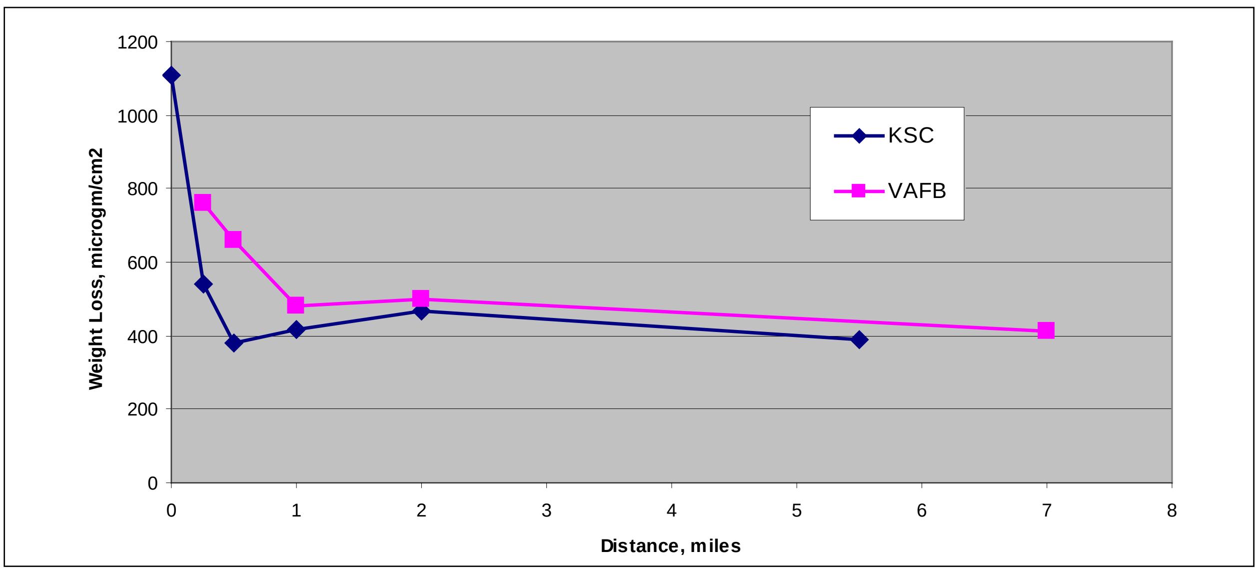

Figure 18. Corrosion of 6061 T6 aluminum at KSC and VAFB vs distance; 1 year values.

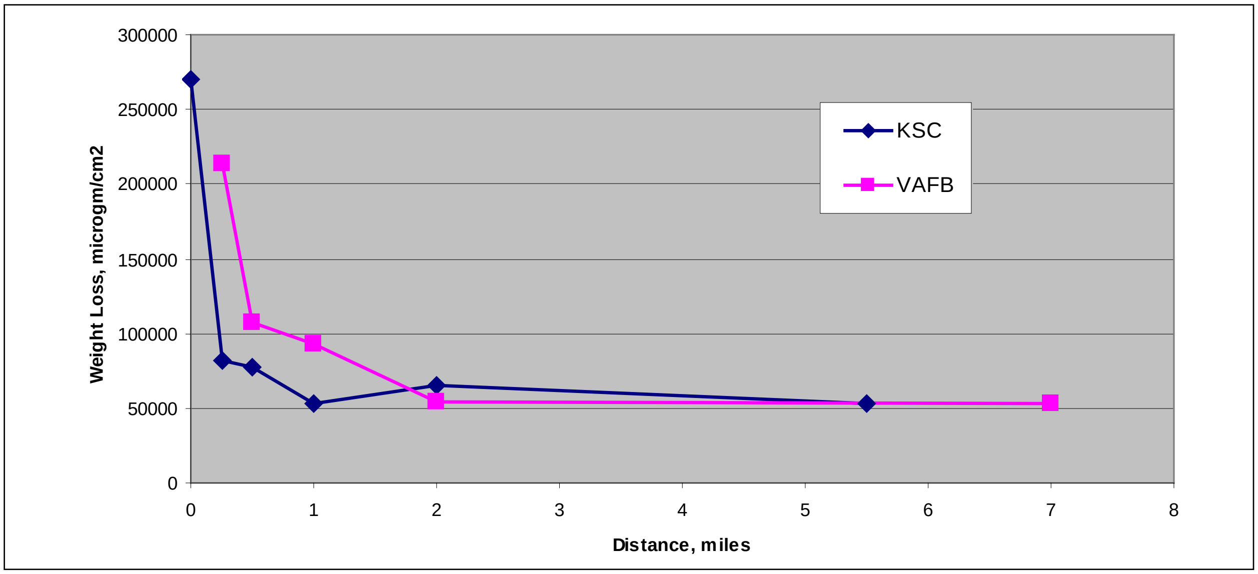

Figure 19. Corrosion of 1010 steel at KSC and Vandenberg AFB vs distance; 1 year values.

The message from such data is that, when coastal corrosion rates are presented, it is very important that distance from the ocean also be given, particularly within the first one-half mile and even within the first mile. Beyond the 2 mile range, the effects of distance appear to be negligible.

These data also illustrate the very important impact on corrosion that results from the location of equipment, aircraft, and structures in relation to the coast. Positioning such assets beyond about 2 miles from the coastline can significantly reduce the impact of corrosion.

A second feature in these data would now indicate very similar relationships for distance effects at KSC and Vandenberg AFB. Both locations rate as very severe and similar. At both locations, chloride levels and corrosion rates level off at a distance of about 2 miles and beyond.

Some results in these data are surprising. These data indicate that Vandenberg is one of the more severe locations in this study. In fact, for similar distances it appears to be more severe than KSC. This difference may be due to the very high atmospheric chloride levels found at Vandenberg and which persist for greater distances inland. This was, at least, surprising to the contractor since, in spite of extensive monitoring at military bases worldwide, it is somewhat surprising to see values this high, particularly on the West Coast. In this respect, Vandenberg ranks near as one of the most severe sites included in this study.

The severity levels at Vandenberg appear to be due mainly to the high atmospheric salt/halogen content in the environment and at levels that appear to remain unusually high for a long distance inland. In other words, the levels do not appear to decrease at the rate "expected" from earlier work at coastal sites. The reasons for these unique features are not yet known but may be due to unique, prevailing wind patterns at Vandenberg. This phenomenon will be studied further. Also, it must be noted that these are only the first 3 months of data. While the data are interesting, it will be important to see whether these patterns persist over four seasons, particularly at Vandenberg.

The data for KSC are particularly important to illustrate the synergistic effects of chlorides and humidity. The KSC Beach site is one of the most severe. For test purposes, this may be an important result. However, that high level of severity is not descriptive of overall conditions at KSC due to the distance effects. For example, one-quarter mile inland (and possibly less) shows results far less severe than at Vandenberg and most other relatively severe sites. These dramatic differences are most likely due to TOW levels due to close proximity to the surf.

Effect of sheltering on corrosion rates

Work is in progress to examine specific exposures designed to quantify the effects of different sheltering scenarios on corrosion in addition to the outdoor exposures. These include the following:

- two Coast Guard ships with exposures above deck and below deck (hangar bays)
- two Navy aircraft carriers with exposures above and below deck
- exposures inside and outside simple aircraft shelter at Tyndall AFB, FL
- exposures inside and outside a shelter at Daytona Beach, FL
- exposures inside and outside storage locations for WRM in Sembach, Germany
- exposures inside and outside aircraft shelter at China Lake, CA
- exposures inside and outside aircraft shelter at Wheeler AAF, HI.

In the case of the test site at Sembach, only the outdoor sample was returned. The reaction rates for all indoor locations were judged to be low by visual appraisals and returning the samples was not deemed worthwhile.

Data that have been obtained shows the important effects of sheltering on reducing corrosion rates at shipboard land-based test sites. The results show that, even a relatively simple open structure/sunshade can reduce corrosion rates by factors of 2:1 or 3:1.

The following lists show a complete set of the early chloride levels, expressed as chloride film thickness in angstroms, and corrosion results expressed as mass loss for one land-based site and one shipboard site:

Tyndall AFB

105 days outside of shelter – 2370 A; chloride
105 days inside of shelter – 1460 A; chloride
2024 aluminum outside – 215 microgm/cm^2
2024 aluminum inside – 48 microgm/cm^2
6061 aluminum outside – 98 microgm/cm^2
6061 aluminum inside – 41 microgm/cm^2
7075 aluminum outside – 234 microgm/cm^2
7075 aluminum inside – 71 microgm/cm^2
Steel outside – 12680 microgm/cm^2
Steel inside – 8157 microgm/cm^2

Coast Guard Ship Harriett Lane

90 days above deck – 12316 A
90 days Hangar Bay – 253 A
2024 aluminum outside – 1829 microgm/cm^2
2024 aluminum inside – 30 microgm/cm^2
6061 aluminum outside – 708 microgm/cm^2
6061 aluminum inside – 18 microgm/cm^2
7075 aluminum outside – 1003 microgm/cm^2
7075 aluminum inside – 22 microgm/cm^2
Steel outside – 48496 microgm/cm^2
Steel inside – 3349 microgm/cm^2

These numbers are highly significant for several reasons. The reactive chlorides represent a major factor in the Air Force corrosion algorithm. These data do not represent the total picture of the corrosion drivers, yet they are very important. This is particularly significant for both locations since it is expected that reduced rainfall and probably reduced TOW will favorably affect these results even more than what is implied by these chloride values. These results continue the trends found in all earlier work to indicate how even simple sheltering procedures may have a large effect on corrosion.

The results for Tyndall fall within the expected range, judging by the contractor's experience with earlier results from shelters. The implied sheltering effects/attenuation ratios for the Coast Guard ship appear far too high, however. The Coast Guard has been questioned about the exact location and conditions surrounding the samples placed in the "Hangar Bay." It appears that, while this location may be called a Hangar Bay, it is not used for this purpose. Furthermore, present indications are that the door to this location is usually closed or only partly open, in contrast to aircraft shelters and even the hangar bays on the aircraft carriers. Therefore, these attenuation factors for the Coast Guard ship are believed to be unrealistically high. At the same time, the data do indicate how small changes in conditions surrounding items that may corrode can be affected by nearby structures.

Shipboard test sites

Analyses were made of the chloride levels obtained during deployments on Navy and Coast Guard ships. Coupon racks were placed both above deck and in a hangar bay, in order to assess how chloride exposure and corrosion rate are reduced under shelter. Chloride levels for coupon racks placed above deck are shown in Figure 20.

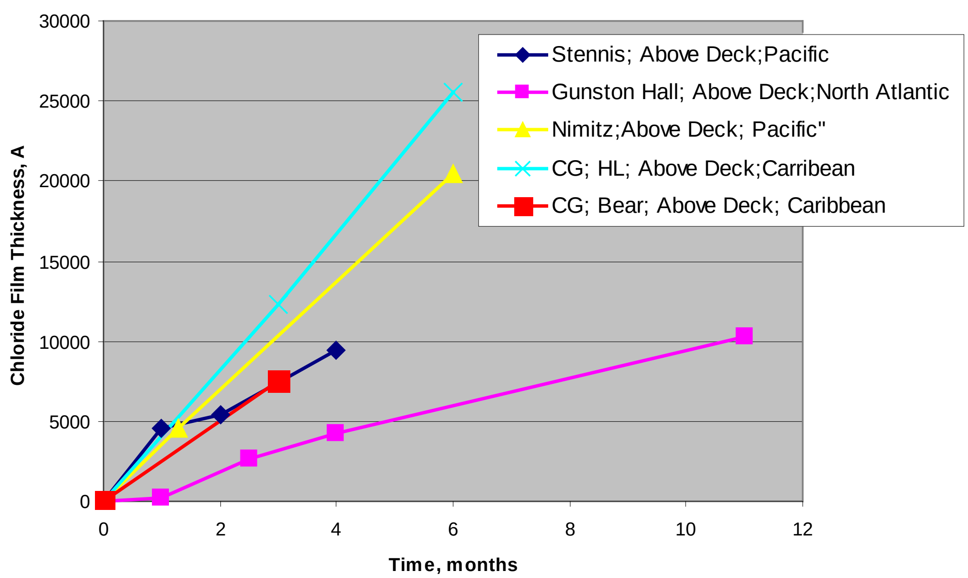

Figure 20. Reactive chloride kinetics above deck for several ships at sea.

Figure 21 presents a summary of all of the atmospheric chloride data available to date for ships-at-sea. Figure 22 summarizes some of the first corrosion data from the same locations at sea, for 6061 T6 aluminum alloy.

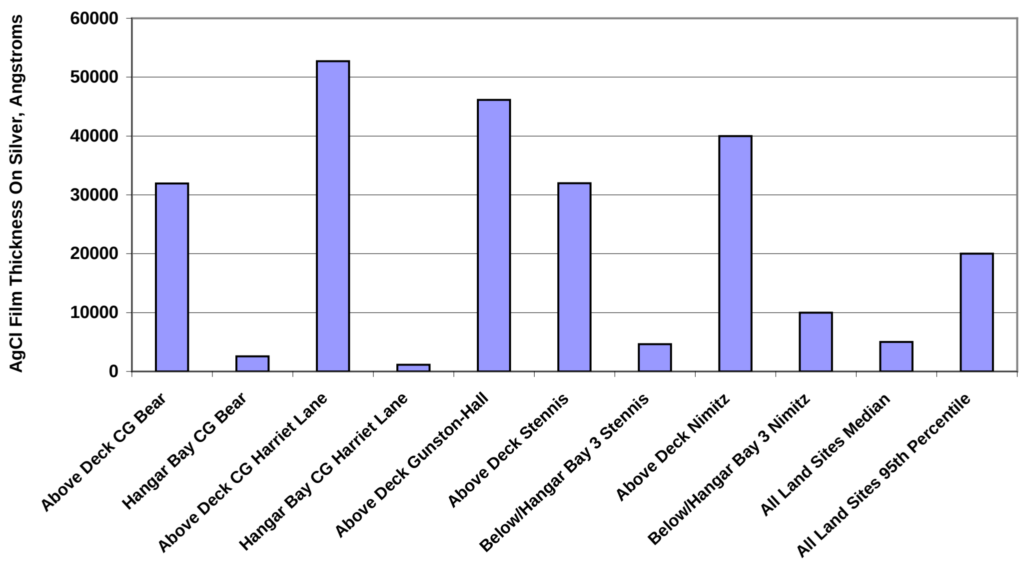

Figure 21. Atmospheric chlorides; comparison of land vs ship data; projected 1 year values.

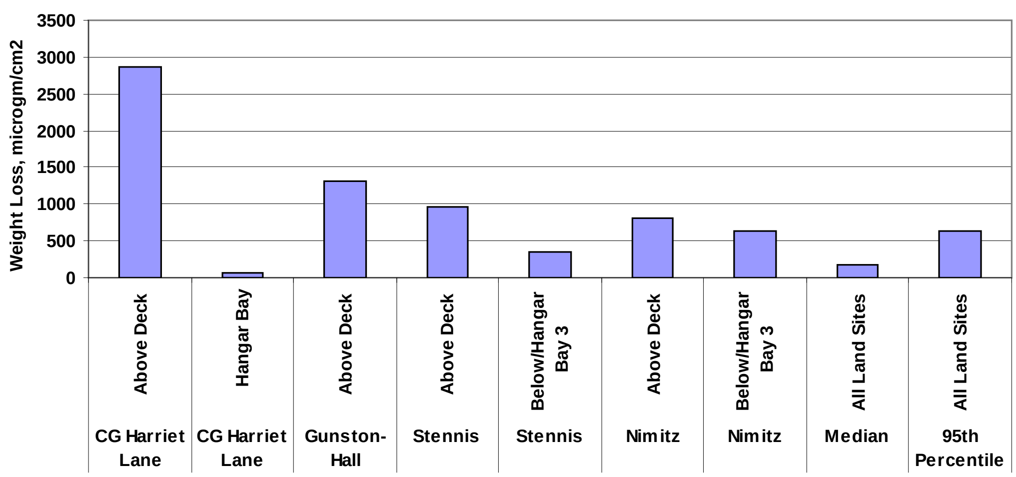

Figure 22. Corrosion of 6061 T6 Al; comparison of land vs ship data; projected 1 year values.

There is little question that at sea and above deck the atmospheric chloride values are well above the extremes found on land even in coastal regions. As important as these data may be, they do not tell the entire story, since

they do not address either corrosion or the very important effect of sheltering.

With regard to the latter, it is evident that very large differences exist between the above-deck locations and any of the more enclosed bays on the ships. This argument will be developed further as corrosion data are developed. However, it also provides a good introduction to the need for further understanding of sheltering effects both on land and sea.

The corrosion data confirm the general conclusions reached from the chloride data. Specifically, the corrosion rates found above deck are higher than land values. Also, the sheltering effects remain large but highly variable. The latter was quite evident between the two carrier deployments into the Pacific. We can only speculate that the differences were not due to small differences in geographic regions. It is more likely that any differences were due to operating practices such as the amount of time bay doors were open and/or any other practices that would have affected air transport and/or humidity levels in Bay 3.

The results of sheltering on the Coast Guard ships are worth noting in view of the apparent very high attenuation factors. In these two cases, it is understood that what is called the hangar bays are typically not used for aircraft storage. This means that the bay door may not be open or at least not to the degree found on the carriers. If this assumption is correct, these data show how possibly small differences in operating practices can have a large effect on sheltering/corrosion.

Land-based test sites

Data have already been presented to illustrate that the benefit in terms of reduced corrosion rates is very substantial even from simple sheltering by structure. New data are being obtained on land from structures that could be described as open aircraft shelters/hangars/tents/etc. The following discussion shows some early data from a broad range of severity levels at Daytona Beach, FL; Tyndall, AFB, FL; and China Lake, CA.

Figure 23 and Figure 24 show results for Daytona Beach. For the data inside the structure, reference is made to High and Low. This refers to samples located at two elevations. One was about 2 ft below the peak of the tent; the other was about 6 ft below the peak or about half way below the peak and ground level.

Figure 25 and Figure 26 show comparable data at Tyndall AFB. Figure 27 and Figure 28 were obtained for an aircraft shelter at the Navy's China Lake facility.

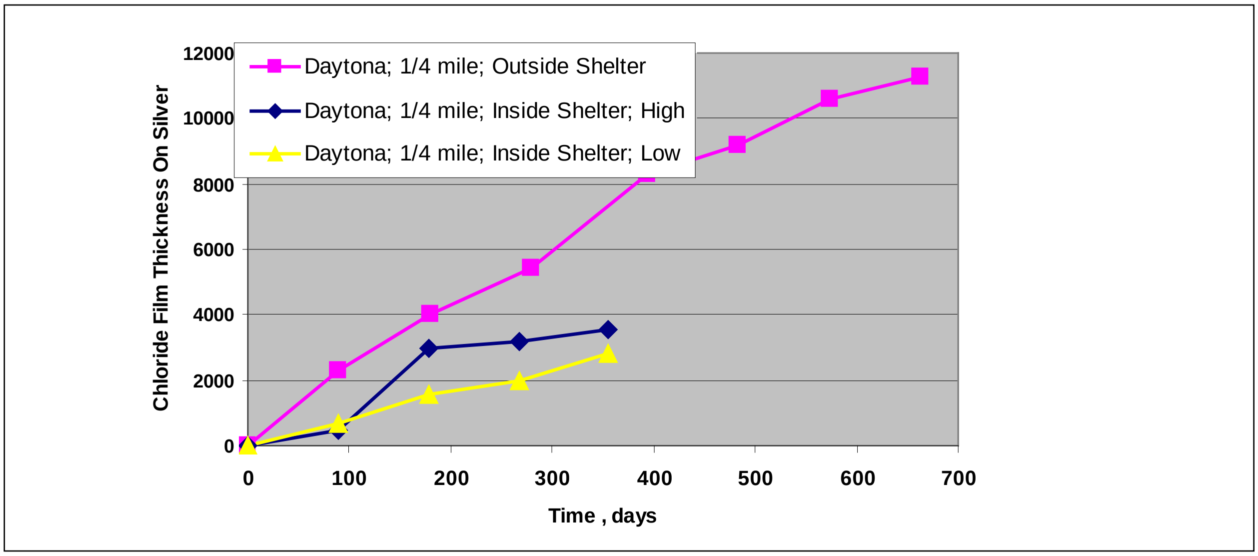

Figure 23. Chloride reaction kinetics on silver sensors inside and outside of open, tent structure at Daytona Beach; 0.25 miles inland.

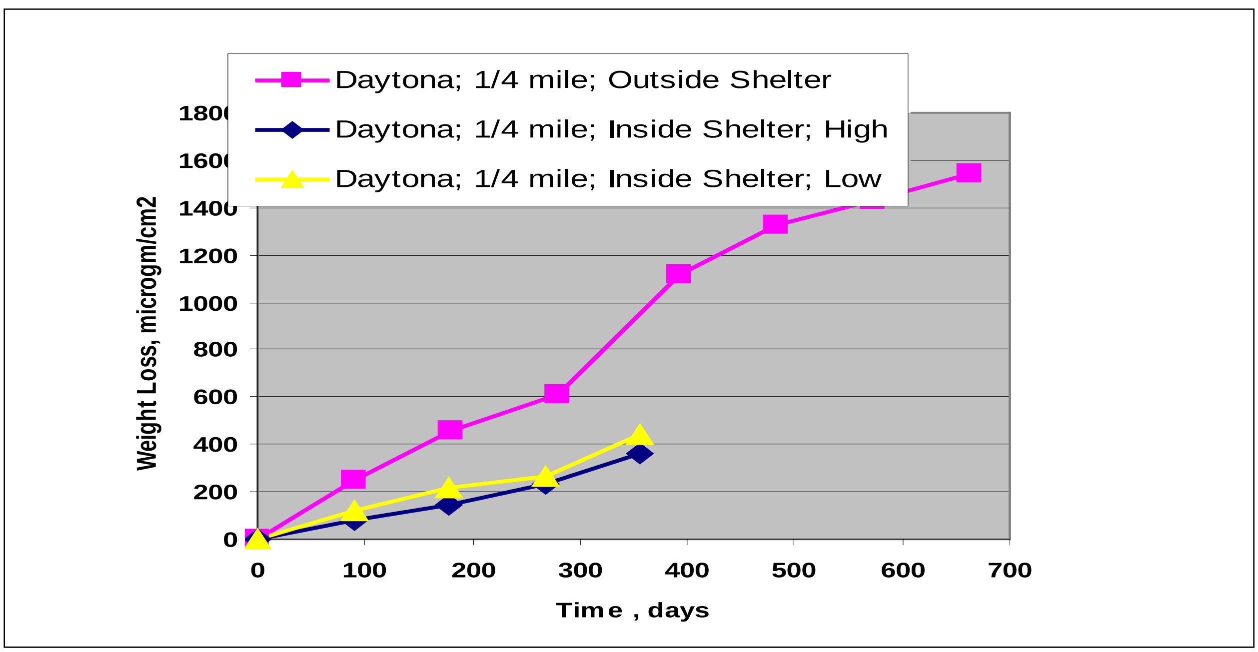

Figure 24. Corrosion of 2024 T3 aluminum inside and outside of open tent structure at Daytona Beach; 0.25 miles inland.

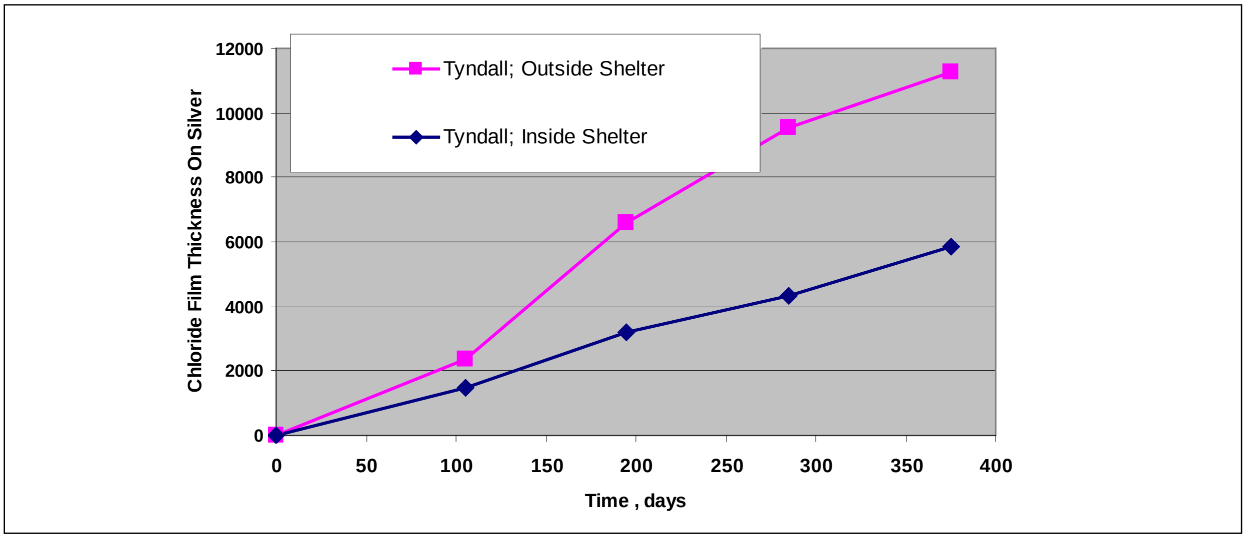

Figure 25. Chloride reaction kinetics on silver sensors inside and outside of open, aircraft shelter at Tyndall AFB.

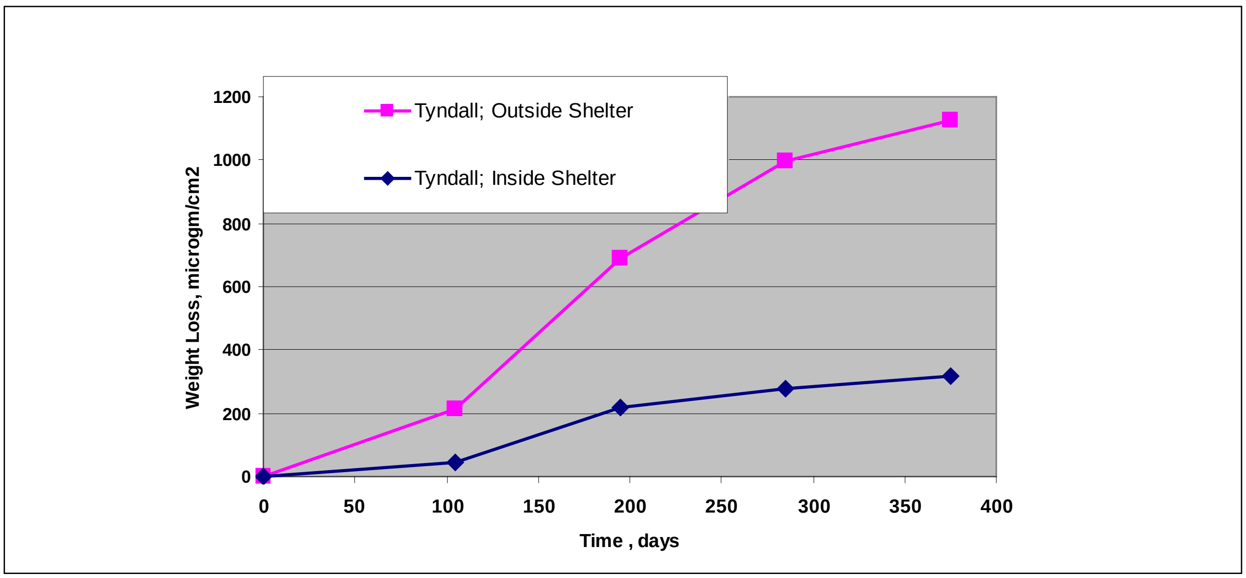

Figure 26. Corrosion of 2024 T3 aluminum inside and outside of open aircraft shelter at Tyndall AFB.

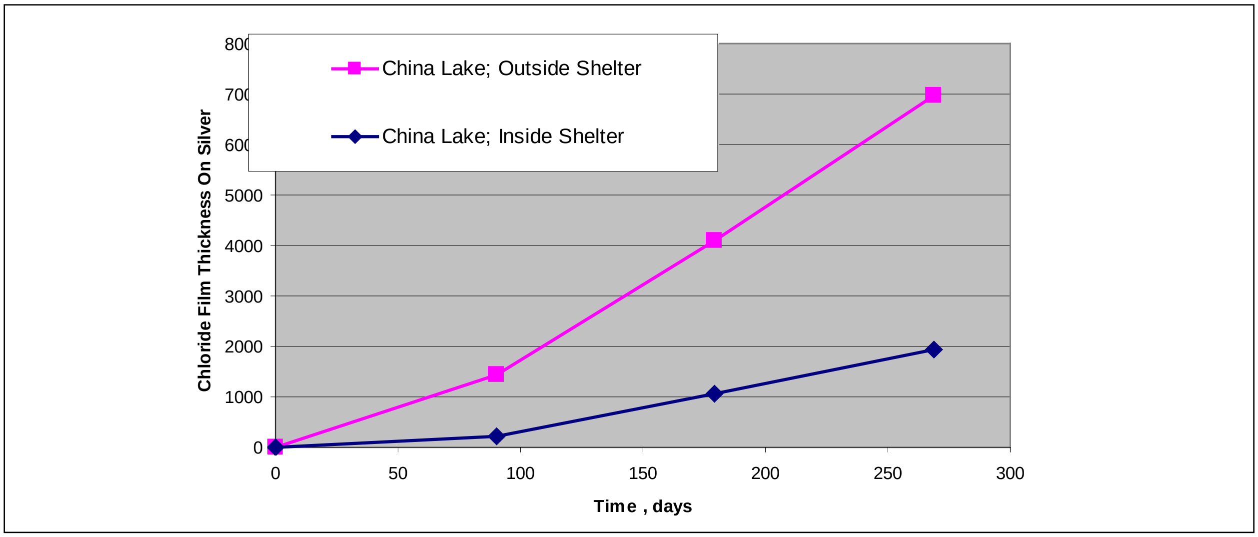

Figure 27. Chloride reaction kinetics on silver sensors inside and outside of open, aircraft shelter at Naval Air Weapons Station China Lake.

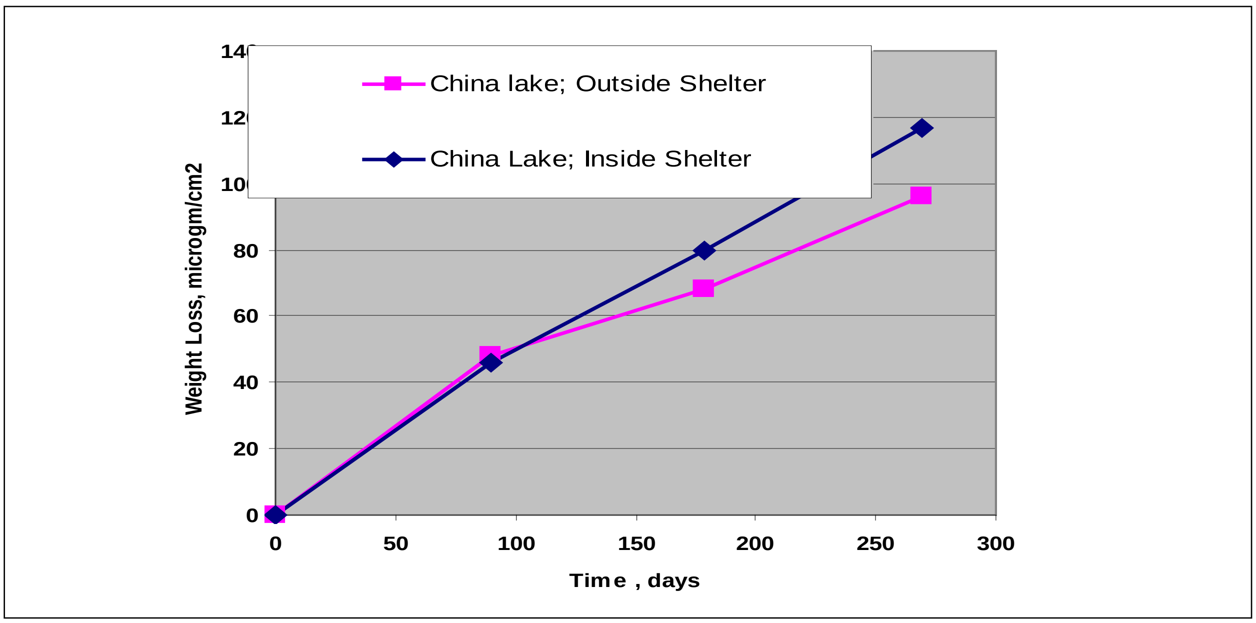

Figure 28. Corrosion of 2024 T3 aluminum inside and outside of open aircraft shelter at Naval Air Weapons Station China Lake.

It is clear that at Tyndall and the inland Daytona sites, corrosion attenuation is being demonstrated. Both Tyndall and inland Daytona are relatively severe sites with Tyndall actually showing higher Environmental Severity Index values. This finding is somewhat significant since these data are suggesting that the greatest benefits may actually occur in those environments where they are most needed. For example, if corrosion at 200 days is compared, an attenuation factor of about 3.5:1 is found at Tyndall, and

2.5:1 at inland Daytona. For the benign location at China Lake, there is no apparent benefit.

Recently, the first (90-day) data were obtained from a metal hangar (a CAP shelter, open at both ends) at Wheeler AAF, HI. Here the outside ESI values were slightly lower than the inland Daytona values, yet the corrosion attenuation for 2024 T3 was approaching 5:1. It is too early to reach any definitive conclusions of whether the shelter structure is giving the higher attenuation. At this time, the more important conclusion concerns the consistent observation of corrosion attenuation by structure, particularly in the more severe environments.

Test site comparisons

Initial analyses have been made for several of the test sites that have historically been used for corrosion exposures. These include KSC, Pt. Judith, Battelle Daytona, and Key West. Vandenberg has been added to this list as a matter of interest and contrast as the only West Coast site. Attempts were made to obtain cooperation from the well known LaQue site to participate in this study were reportedly not successful as first, but this situation has changed. Samples are now in place at LaQue, and it is likely that data will be obtained over at least 9 months before this site closes.

Among the diverse and numerous sites being studied in this work, several have historically been used for corrosion exposures. It was considered useful to develop a comparison among these sites for monitoring conducted in a consistent manner. Some of the data at sites for which the monitoring is mostly completed are shown in Figure 29 – Figure 31. This list will eventually be updated with data from LaQue and Corrpro. These are sites at which monitoring was more recently begun.

These data show a very large difference among the various sites. However, the relative rankings would appear to depend on the particular metals that are being compared. It is somewhat interesting to note the high severity of the KSC site, yet among these sites KSC is not the one with the highest reactive chloride. This behavior is most likely due to a very high TOW at this site because of its very close proximity to the ocean/surf. Whether this is the correct explanation, the main lesson to be learned from these data is the need to carefully define the sample placement location, as shown earlier for the data in Figure 16 — Figure 19. For example, it would be inadequate to simply say that samples were exposed at KSC without closely de-

fining the distance effects, since moving steel samples only one-quarter mile inland vs the beach site would change its ranking in Figure 31 from one of the most severe to almost the least severe. This need would apply to any site in proximity to an ocean.

It is also shown in earlier data for Pt. Judith, where the difference is large between the front and back of the test lot. Some of these details are not yet available, but the intent will be to define locations for each of these sites. Again, it should be emphasized that these are early results, and it will be interesting to see how the data develop over a full year of study.

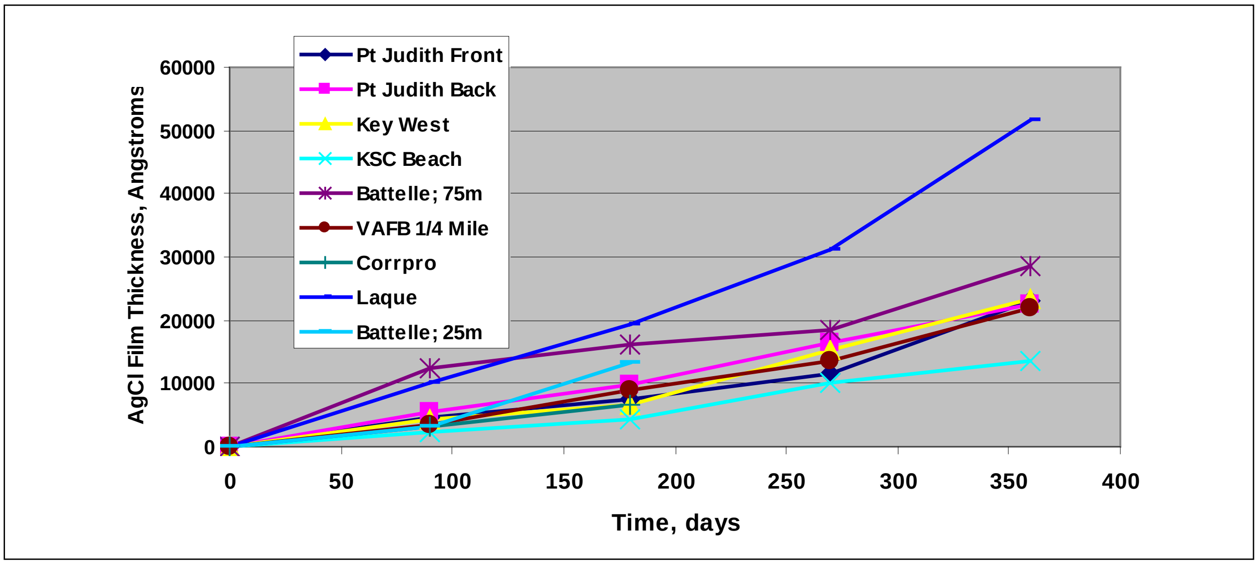

Figure 29. Comparison of atmospheric chloride levels among commonly used test sites.

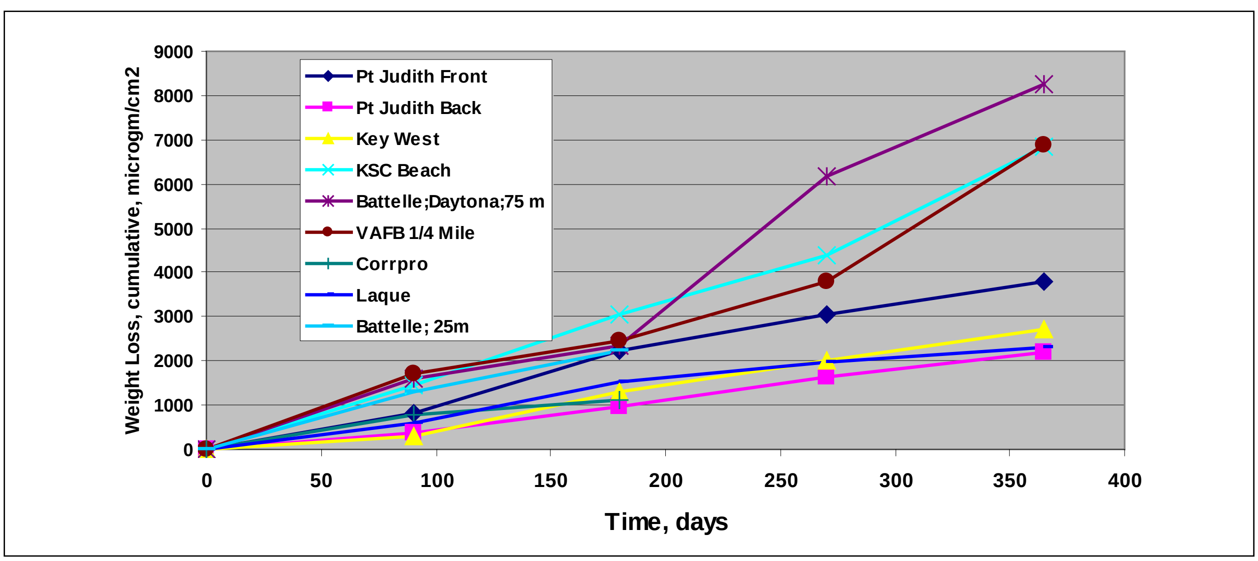

Figure 30. Comparison of corrosion of 2024 T3 aluminum among commonly used test sites.

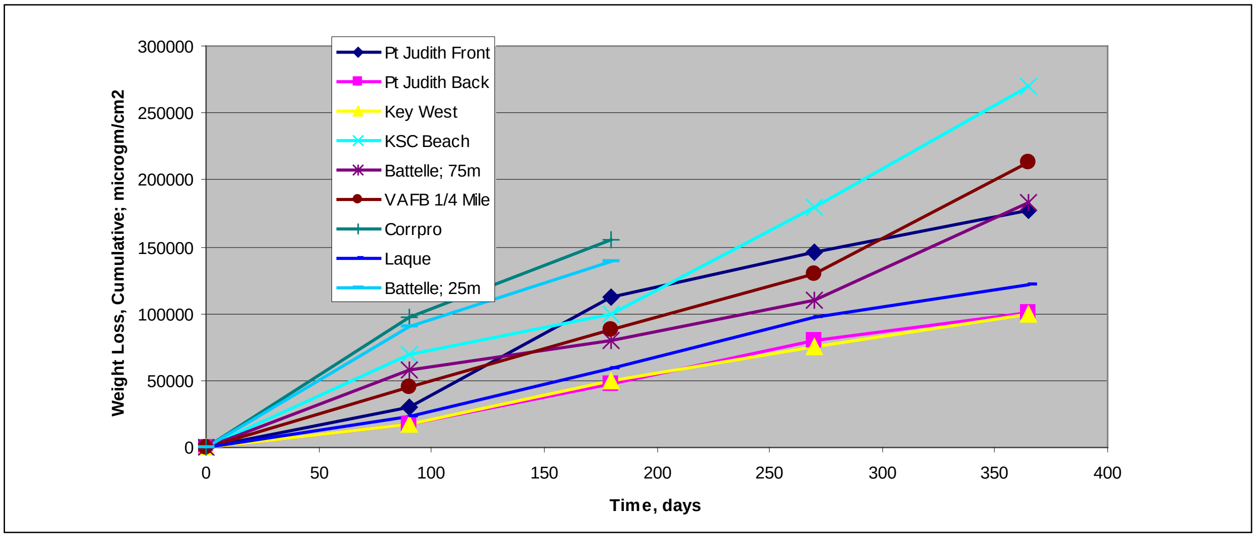

Figure 31. Comparison of corrosion of 1010 steel among commonly used test sites.

4 Metrics

The following metrics were incorporated into CPC Project AR-F-311:

- ASTM G1, *Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens*.
- ASTM B825, *Standard Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples*.

5 Economic Summary

This section is not applicable to CPC Project AR-F-311.

6 Recommendations

It is recommended that these data be incorporated into a database to support a predictive corrosion rate model that will help designers and maintenance managers make the best material selection, design, and maintenance decisions to minimize the cost and impact of corrosion on DoD assets.

It is recommended that future beneficial technologies based in part on these corrosion rate data should be considered for adoption as part of the DoD Corrosion Prevention and Control Program.

It is recommended that the results of this study be included by reference in the DoD Corrosion Prevention and Control Planning Handbook, which is available for download at http://www.dodcorrosionexchange.org.

7 Implementation

The data collected in this study have been incorporated into FY06 CPC project FAR-15, “Development of Corrosion Indices and Life-Cycle prediction for Equipment and Facilities.” The objective of that work is to develop a software-based model and predictive life-cycle tool for optimizing design, production, and construction decisions.

8 Conclusions

The chloride contribution to corrosion is an important factor in atmospheric corrosion rate, but it should be recognized that this is only one part of a complex, synergistic relationship between chlorides and other critical environmental variables. In particular, various measures of moisture in the atmosphere play a very important role. High TOW in combination with high chloride concentration produces a higher corrosion rate than would be expected from either effect individually.

A marked correlation between chloride concentration and corrosion rate exists as a function of distance from the ocean. For measurements taken at various distances from the ocean, early data show strong differences among atmospheric chloride levels but far greater differences in corrosion rates. These results have been observed, but not yet explained using current corrosion models. If these models hold true, however, the corrosion differences have to be accounted for by significant differences in relative humidity/TOW and, to a lesser extent, rainfall.

The observed corrosion rates varied strongly with the degree of sheltering under which the coupons were exposed. Sheltered coupons corroded significantly slower compared to the coupons exposed to the general weather.

This project, in conjunction with previous related projects, has been successful in establishing corrosion rates and impact for a wide variety of DoD installations and assets. The high-quality data sets acquired in this study will be directly applicable to DoD decisions about appropriate materials selection, facility location, and equipment sheltering to protect critical infrastructure from the corrosive effects of the marine environment.

Appendix A: Samples for OSD Corrosion Monitoring Program

Coast Guard Sites

Coast Guard Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Humboldt Bay; Samoa, CA	20 ft from ocean	15	5/24/2006	2/14/2005
Manistee, MI		15	5/31/2006	2/14/2005
San Diego, CA	30 ft from ocean	16	6/12/2006	2/15/2005
New Orleans, LA	lost in hurricane, site discontinued	6	8/20/2005	2/16/2005
Boston, MA		16	6/28/2006	2/18/2005
Miami Bch., FL	6' off ground, 42' from water, facing	15	5/24/2006	2/22/2005
Portsmouth, VA		15	5/31/2006	2/22/2005
Seattle, WA	20 ft Horiz & 20-30 ft Verti	15	6/2/2006	2/23/2005
USCGC Harriet Lane; Portsmouth	Outside	7	2/4/2006	7/30/2005
USCGC Harriet Lane; Portsmouth	Inside	7	2/4/2006	7/30/2005
USCGC Bear; WMEC 901; Portsmouth	Outside	6	3/23/2006	9/7/2005
USCGC Bear; WMEC 901; Portsmouth	Hangar	6	3/23/2006	9/7/2005

Army Sites

Army Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Wheeler		21	3/9/2007	3/14/2005
Wheeler; CAP/Open Metal Hangar		13	3/9/2007	1/30/2006
Rock Island		15	7/20/2006	4/14/2005
Univ of Hawaii/Army Pacific Rim				
Coconut Island		27	5/2/2007	1/15/2005
Lyon Arboretum		27	5/2/2007	1/15/2005
Campbell		18	5/2/2007	3/4/2005
Ewa Nui		25	5/2/2007	3/4/2005
Waipahu		25	5/2/2007	3/4/2005
Kahuku		26	5/2/2007	3/4/2005
Little Goose Lock & Dam		14	5/25/2006	3/9/2005
CG Yard; Baltimore		15	6/5/2006	3/9/2005
Ft. Irwin	Bike Lake, Airfield	15	6/17/2006	3/10/2005
Ft. Eustis		14	5/30/2006	3/7/2005
Hunter AAF		14	5/24/2006	3/15/2005
Hunter AAF	resumed	3	3/7/2007	9/5/2006
Ft. Polk		14	5/24/2006	3/14/2005
Ft. Hood		14	6/19/2006	4/6/2005
Ft. Rucker		14	6/20/2006	4/4/2005
Ft. Drum		12	4/24/2006	4/1/2005
Ft. Irwin	El Grazio	14	6/16/006	4/8/2005
Ft. Irwin	Warehouse area	14	6/16/006	4/8/2005
Ft. Irwin	Barstow-Daggett Heliport	14	6/16/006	4/8/2005
Ft. Irwin	Main Gate	14	6/16/006	4/8/2005
Ft. Irwin	Waste water plant	14	6/16/006	4/8/2005
Vandenberg	1/2 mile Rod & Gun club Bldg 1521	13	7/6/2006	6/2/2005

Army Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Vandenberg	1/4 mile MDA/Boeing Bldg 988	13	7/6/2006	6/2/2005
Vandenberg	1 mile SLC 6, Bldg 392	13	7/6/2006	6/2/2005
Vandenberg	2 miles Airfield	13	7/6/2006	6/2/2005
Vandenberg	7 miles	13	7/6/2006	6/2/2005
Ft. Campbell		12	6/2/2006	6/1/2005
San Andres, Colombia		13	7/15/2006	5/11/2005
Bogata, Colombia		13	7/15/2006	5/13/2005
Riohacha, Colombia		13	7/15/2006	5/10/2005
Tres Esquinas, Colombia		12	7/15/2006	6/2/2005
Schofield Barracks, HI		14	9/6/2006	7/22/2005
Ft. Wainwright		12	5/1/2007	5/4/2006
Exuma Airport, Bahamas		6	5/6/2007	11/15/2006
Ft. A.P. Hill	Inside magazine 2	3		3/29/2007
Ft. A.P. Hill	Inside magazine 12	3		3/29/2007
Ft. A.P. Hill	Outside magazine 12	3		3/29/2007

Navy Sites

Navy Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
USS Gunston Hall			12/16/05	1/5/2005
NAS Sigonella			6/27/05	6/26/2004
USS Nimitz – above deck		18	11/8/2006	5/06/2005
USS Nimitz – below deck		18	11/8/2006	5/06/2005
China Lake under shelter		12	1/25/2007	1/26/2006
China Lake outside shelter		12	1/25/2007	1/26/2006
USS Halyburton - above deck			6/12/2006	
USS Halyburton - below deck			6/12/2006	
Whidbey			5/20/2007	3/6/2007
Whidbey			5/20/2007	3/6/2007
Whidbey			5/20/2007	3/6/2007

Air Force Sites

Air Force Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Pt Judith – Back of Lot		24	4/4/2007	3/27/2005
Pt. Judith – Front of Lot		24	4/4/2007	3/27/2005
Westover ARB		21	2/20/2007	5/1/2005
BBSR Station		12	2/24/2006	2/25/2005
BBSR Prospect		12	2/24/2006	2/25/2005
BBSR St. Davids		12	2/24/2006	2/25/2005
Stewart ANG		20	2/21/2007	6/8/2005
Lackland AFB		15	9/18/2006	6/22/2005
Sembach	Bldg 16; heated in winter	12	7/12/2006	6/28/2005
Sembach	Bldg 15; humidity controlled	12	7/12/2006	6/28/2005

Air Force Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Sembach	outdoors	12	7/12/2006	6/28/2005
Sembach	Bldg 17; vented for POL trucks	12	7/12/2006	6/28/2005
Tyndall AFB	Outside shelter	15	4/19/2007	8/31/2005
Tyndall AFB	Inside shelter	15	4/19/2007	8/31/2005
Mansfield		14	4/3/2007	11/15/2005
Savannah ANG		10	3/2/2007	5/11/2006
Moody ANG		12	5/4/2007	5/12/2006
Hickam	Test Bench Area, AIS Shop, Bldg 3386	12		6/28/2006
Hickam	Test Bench Area, AIS Shop, Bldg 3386	3		3/19/2007
Hickam	Quality Assurance, Room #4, Bldg 3386	12		6/28/2006
Hickam	Training Room #16, Bldg 3386	12		6/28/2006
Hickam	On LTi Utility Station outside F-15 AGE Shelter	11	4/15/2007	7/13/2006
Hickam	On LTi Utility Station off F-15 Ramp along Loko Drive	11	4/15/2007	7/13/2006
Hickam	On LTi Utility Station #1 inside Bldg 1045	11	4/15/2007	7/9/2006
Hickam	Inside Shelter #3, Bldg 1045	11		7/9/2006
Hickam	Inside F-15 AGE Shelter	11		7/9/2006
Hickam	F-15 Sunshade Shelter #16, Left Side Center Upright Support, 25 feet high	8	3/3/2007	7/18/2006
Hickam	F-15 Sunshade Shelter #16, Left Side Center Upright Support, 12 feet high	8	sent 4/13/07	7/18/2006
Hickam	F-15 Sunshade Shelter #10, Left Side Center Upright Support, 25 feet high	8	3/3/2007	7/18/2006
Hickam	F-15 Sunshade Shelter #10, Left Side Center Upright Support, 12 feet high	8	sent 4/13/07	7/18/2006
Hickam	F-15 Sunshade Shelter #08, Left Side Center Upright Support, 25 feet high	8	3/3/2007	7/18/2006
Hickam	F-15 Sunshade Shelter #08, Left Side Center Upright Support, 12 feet high	8	sent 4/13/07	7/18/2006

Air Force Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Hickam	F-15 Sunshade Shelter #02, Left Side Center Upright Support, 25 feet high	8	3/3/2007	7/18/2006
Hickam	F-15 Sunshade Shelter #02, Left Side Center Upright Support, 12 feet high	8	4/18/2007	7/18/2006
Hickam	HIANG/Wahiawa - Outside	6	5/21/2007	11/21/2006
Hickam	HIANG/Wahiawa - Inside	6		11/21/2006
Hickam	Hangar 35 Dk2 ~240' from hangar door	4	3/9/2007	11/27/2006
Hickam	Hangar 35 Dk1 ~60' from hangar door facing dock	4	3/9/2007	11/27/2006
Hickam	Outdoors on bld 2025 (shade ~ half day)	4	3/9/2007	11/27/2006
Louisville ANG	Materials Storage Area	9	3/27/2007	6/8/2006
Long Island, NY	outside front door of Hangar Bay. Rack mounted ~6 ft from ground, and facing North.	9	3/27/2007	6/15/2006
Long Island, NY	outside front door of Hangar Bay. Rack mounted ~6 ft from ground, and facing North.	6		12/5/2006
Patrick ANG		13	3/16/2007	4/28/2006
Yokota, Japan		3	4/15/2007	1/24/2007
Dobbins, GA		3	6/10/2007	3/10/2007

NASA Sites

NASA Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Key West		15	6/22/06	3/8/2005
KSC Corrosion Test Site	Beach, outside	6	7/20/06	1/6/2006
KSC Corrosion Test Site	Beach	16	7/20/06	3/15/2005
KSC Corrosion Test Site	1/4 mile	13	7/20/06	6/3/2005
KSC Corrosion Test Site	1/2 mile	13	7/20/06	6/3/2005
KSC Corrosion Test Site	1 mile	13	7/20/06	6/3/2005
KSC Corrosion Test Site	2 mile	13	7/20/06	6/3/2005
KSC Corrosion Test Site	5.5 mile	13	7/20/06	6/3/2005

NSF Sites

NSF Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Antarctic		4	mid Feb 06	10/20/2005
Antarctic		10	mid Aug 06	10/20/2005

Miscellaneous Sites

Miscellaneous Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Daytona	1/2 mi riverside fence	16	3/7/2007	8/26/2005
Daytona	beach site, 75 meters	12	5/27/2007	11/2/2005
Daytona	Doghouse	12	2/23/2007	11/4/2005
Daytona	Shelter: 2 ft from top	12	1/20/2007	1/19/2006
Daytona	Shelter: 4 ft from top	12	1/20/2007	1/19/2006

Miscellaneous Locations	Comments	Total Exposure Months	Last Replaced or Removed	Beginning Date
Daytona	Shelter: side	3	4/10/2007	1/10/2007
Daytona	Shelter: top peak	3	4/10/2007	1/10/2007
Daytona	45 degree rack, ocean site	9	5/8/2007	8/9/2006
Daytona	upright near rack, ocean site	9	5/8/2007	8/9/2006
West Jefferson; 45 degree		6	2/10/2007	8/12/2006
West Jefferson; upright		6	2/10/2007	8/12/2006
Laque, Kure Beach, NC	~ 25 meters from mean high tide	15	6/6/2007	3/1/2006
Corrpro Company, OC, NJ	Sea Isle City, NJ, approximately 10 miles south of Ocean City , card ~100yds from Mean high tide	9	3/14/2007	9/15/2006
Perry, FL (Big Top)	36 wide x 30 Long shelter full cover on the 30' length side at 4 feet from the ground	3	5/28/2007	2/1/2007
Perry, FL (Big Top)	36x30 shelter on the end panel at 8 feet from the ground	3	5/28/2007	2/1/2007
Perry, FL (Big Top)	open field / chain link fence at 6' feet off the ground	3	5/28/2007	2/1/2007
Perry, FL (Big Top)	open air 80' wide x sun shade (no ends or sides) at 12'feet of the ground	3	5/28/2007	2/1/2007
University of Puerto Rico, Mayaguez, PR	on roof facing wind	4	5/23/2007	2/23/2007

Appendix B: Representative Field Site Installations

Figure A1. Test rack on USCGC Bear; above deck.

Figure A2. Test rack at Bogota site, Colombia.

Figure A3. Test rack at Riohacha site, Colombia.

Figure A4. Test rack at Fort Irwin, warehouse area.

Figure A15. Test rack at Kennedy Space Center beach site, 90 days.

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14. ABSTRACT

This report documents a corrosion rate study performed for the Office of the Secretary of Defense (OSD) under the Corrosion Prevention and Control Program (CPC) in which standardized coupon test racks were set up in numerous marine locations at military and other government installations in the United States and overseas, including test sites on Navy and Coast Guard ships. The test sites encompass a large variety of locations, both in open exposure and sheltered environments. The principal objective of the study was to collect a large, standardized sample of data to be used in subsequent development of a computer-based model and corrosion-rate prediction tool. An analysis of the collected data indicate that corrosion rates decrease significantly when an installation's distance from an ocean exceeds 2 miles. The data analysis also shows that corrosion rates for military equipment can be reduced even by providing a simple shelter.

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Battelle, corrosion rate assessment, chloride, military equipment

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